University of Cincinnati

Date: 7/15/2015

I, Nathaniel E Foust , hereby submit this original work as part of the requirements for the degree of Master of Arts in Anthropology.

It is entitled:

A Spatiotemporal GIS Analysis of GPS Effects on Archaeological Site Variability

Student's name: **Nathaniel E Foust**

This work and its defense approved by:

Committee chair: Alan Sullivan, Ph.D.

Committee member: Susan Allen, Ph.D.

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A Spatiotemporal GIS Analysis of GPS Effects on Archaeological Site Variability

A thesis submitted to the

Division of Graduate Studies and Research
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS

in the Department of Anthropology
of the McMicken College of Arts and Sciences

2015

by

Nathaniel E. Foust

B.A., Bowling Green State University, 2012

Committee:
Alan P. Sullivan, III, Chair
Susan E. Allen

Abstract

Regional analyses of archaeological phenomena are heavily dependent upon accurate spatial data. This condition is especially true concerning the practice of surface archaeology, which relies almost exclusively on spatial patterns to infer culture change and culture process. Inferences and conclusions drawn from these data are used to answer both particularistic and theoretical questions regarding ancient human behavior. It is thus imperative that the data used in surface archaeology research be as accurate and reliable as possible, if we aim to produce rigorous scientific results.

The Upper Basin Archaeological Research Project (UBARP) provides an excellent opportunity to test the veracity of regional level spatial data. Since 1989, UBARP has discovered over 2,200 archaeological phenomena across nearly 24 km^2 of the Upper Basin, Grand Canyon, northern Arizona. The work has been carried out primarily through intensive surveys, facilitated by the use of numerous GPS devices since 1994. Because these phenomena were recorded prior to and during the evolution of GPS technology, the question of their spatial accuracy was raised. Ground-truthing field work was conducted in 2014 to provide comparative data for this study, which proposed that the locations and patterning of archaeological features would steadily increase in accuracy over time with the employment of GPS technology.

The results of this study suggest that recording archaeological features with GPS has provided a significant improvement in the spatial reliability and inferential potential of surface archaeology. For this reason, interpretations of the culture history of this region, and others, drawn from pre-GPS surveys may be suspect for their accuracy. Based on the results of this study, remediation of archaeological surveys conducted prior to the use of GPS is highly encouraged.

Acknowledgments

The crafting of this thesis would not have been possible without the consistent critiquing and guidance of my advisor, Dr. Alan Sullivan. His remarks concerning the approach and direction of this study, as well as his support along my path to becoming an archaeologist has been invaluable. Gratitude is also due to Dr. Susan Allen, whose encouraging comments have helped refine not only this thesis, but also my early trajectory in grad school and my interest in pursuing the spatial elements of archaeology.

Further thanks are due to Nikki Berkebile, Mike Kraus, Dayna Reale, and Ryan Washam, who, with no stake in this study, journeyed out to the Basin to help with data collection during the ground-truthing and surveying component. To the other faculty members, family, and friends from Cincinnati who have shared my experiences and lent support during this, at times arcane process, I offer my sincerest appreciation.

Table of Contents

List of Tables

List of Figures

Chapter 1 – Introduction

The rate at which archaeological surveys can be conducted has dramatically improved over the last two decades thanks to the introduction of the global positioning system (GPS) into the archaeologist's toolkit (Conolly and Lake 2006; Howard 2007; Wheatley and Gillings 2002). However, like any other tool at the disposal of the archaeologist, the use of GPS brings a unique set of benefits and challenges to the field that may create unintentional biases in the results of academic research and cultural resource management (McCoy and Ladefoged 2009:282; Wheatley and Gillings 2002:84). The intent of this thesis is to closely examine some of the more conspicuous effects that GPS may have on the characteristics of the survey-based archaeological record. Specifically, I hope to address how GPS has affected (1) the accuracy with which we map archaeological sites, (2) the spatial distribution of sites, (3) the non-archaeological attributes associated with sites, and (4) the rate of discovery and variability of site types. I propose that GPS, and its improved capabilities over the last two decades, has had a positive, statistically significant impact on these four characteristics of the archaeological record.

In order to test this hypothesis, I will draw from the accumulated spatial and archaeological data of the Upper Basin Archaeological Research Project (UBARP). This project, which has been conducted since 1989 in the Upper Basin area of the eastern Grand Canyon, Arizona, has logged more than 2,200 archaeological sites with intensive surveys in an area covering nearly 24 km^2 (Figures 1.1 and 1.2) (Sullivan et al. 2002). The durational and spatial extent of this project makes it an excellent candidate for analyzing diachronic changes in both *how* archaeological sites were recorded and *what types* were recorded. Furthermore, UBARP straddles a period of time that includes surveys from before GPS was available. This advantageous time frame provides an ideal setting for examining the characteristics of the archaeological record both prior to and during the evolution of GPS technology.

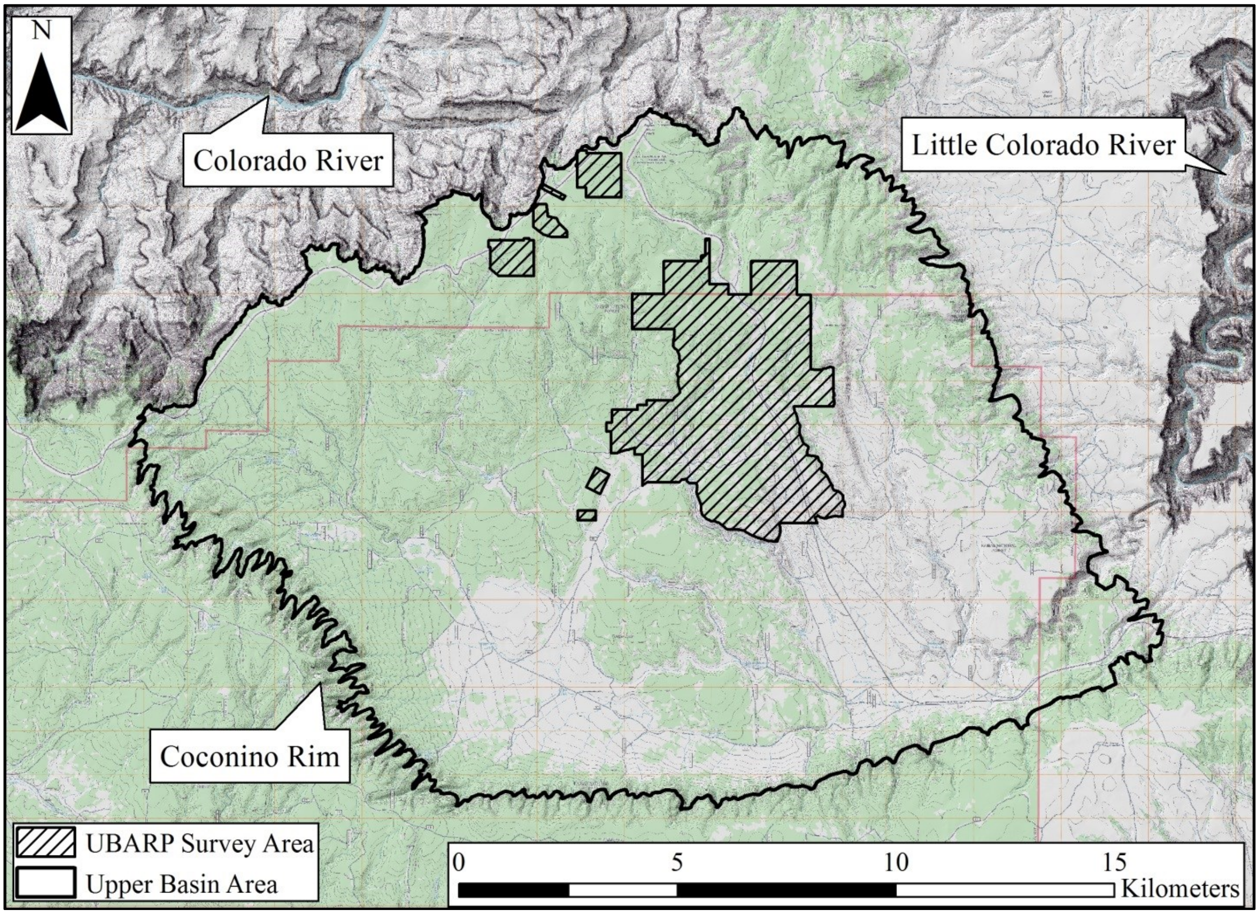


Figure 1.1. Extent of the UBARP survey area and the Upper Basin.

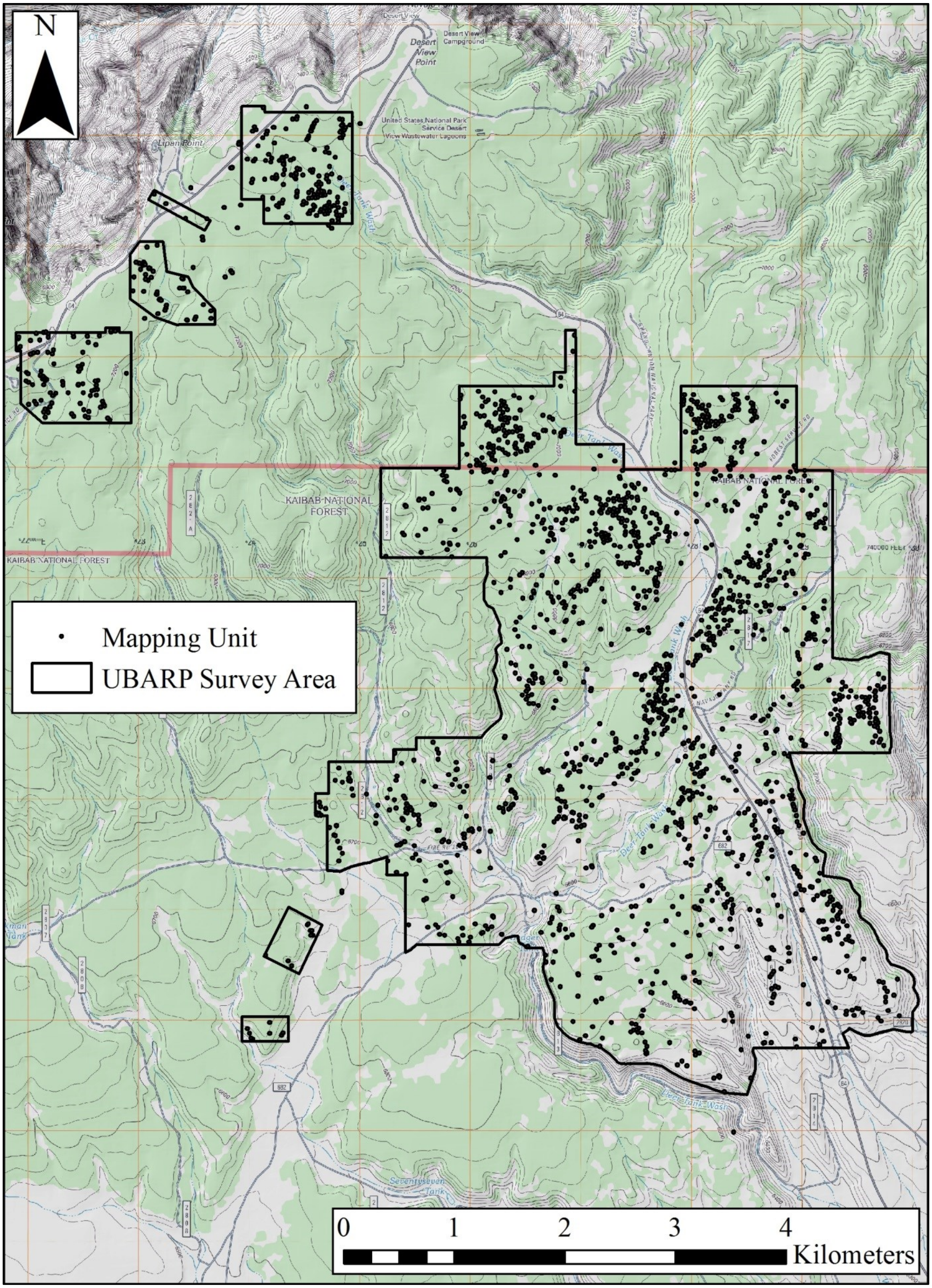


Figure 1.2. UBARP survey area and Mapping Units (archaeological phenomena).

Upper Basin Environment

This study and the data upon which it is based involve a unique physiographic region of the Grand Canyon's South Rim, known as the Upper Basin. The Upper Basin is a downfaulted section of the northeastern Coconino Plateau, which overlooks the Grand Canyon on its northern edge, and is bounded in the south and west by the steep-walled Coconino Rim (Figure 1.3) (Fugate 2003:9). Elevationally, the Upper Basin peaks at 2,256 m asl along its northern rim, and slopes down to 1,869 m asl, where it meets the Coconino Rim (Sullivan et al. 2001:367). The region's topography is characterized by rough, low hills and shallow ravines in the north that smooth to rolling flatlands in the south (McNamee 2003). The vegetation of the Upper Basin is primarily dense pinyon-juniper woodland that thins southward, with some ponderosa in the west (Figure 1.4) (Vankat 2013). Patches of sagebrush and grass are scattered throughout the northern woodlands, and make up the predominant land cover in the southern flatlands (Sullivan et al. 2015). Annual precipitation for the region is around 15.3 inches (389 mm), with the driest and wettest periods of the year occurring in early and late summer, respectively (Sullivan et al. 2002:53; Sullivan and Ruter 2006).

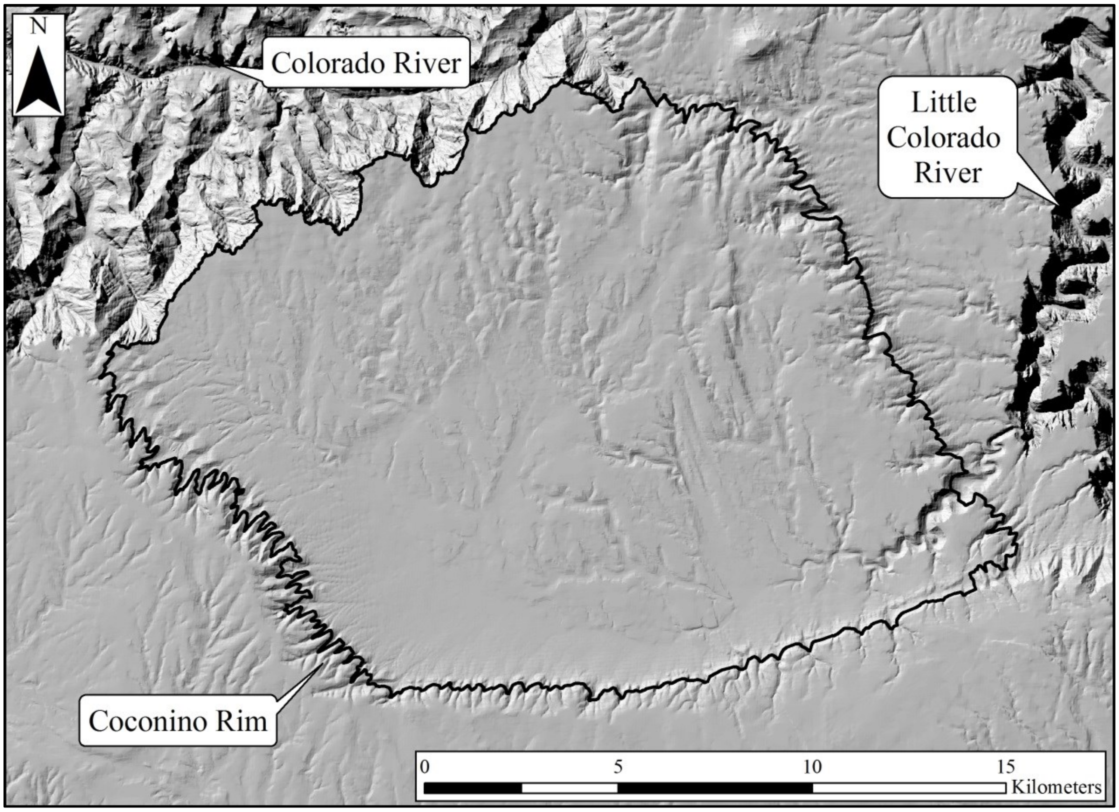


Figure 1.3. 10 meter hillshade of the Upper Basin area, Grand Canyon.

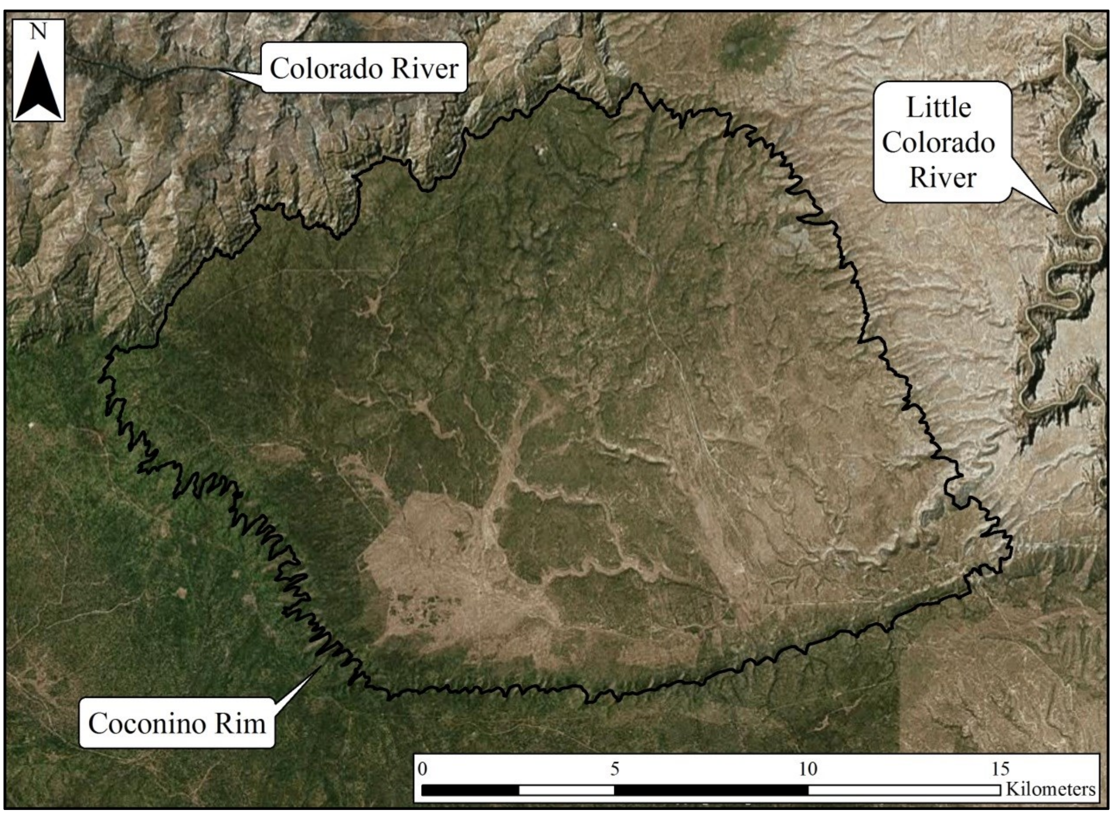


Figure 1.4. 0.3 meter Landsat image of the Upper Basin area, Grand Canyon.

Archaeological Surveys and GIS

Archaeology is, by its methodical nature, a spatially intensive discipline (Burger and Todd 2006; Hey 2006; Lock and Molyneaux 2006; Wheatley and Gillings 2002). The process of investigating archaeological materials presents the archaeologist with two fundamental questions: *what* is it (descriptors, typology, purpose, etc.), and *where* is it (contextually, stratigraphically, regionally, etc.)? The answers to these questions often set the archaeologist onto further paths of inquiry (Ridges 2006). Those same answers also produce the basic building blocks of all geospatial data: attributes and locations. Because of these shared common denominators, archaeological data and geographical methods of data storage and visualization are naturally suited to each other (Conolly and Lake 2006; Daly 2009).

Perhaps even more than excavation, inferences and conclusions generated from archaeological surveys are wholly dependent upon the spatial attributes of their data for validation (Banning 2002). Therefore, minor adjustments in site locations can have a prodigious effect on how archaeologists interpret the characteristics and variability of a region's archaeological record, as this study will show (Kvamme 1999). To test the impact of these adjustments, archaeological fieldwork was conducted in the autumn of 2014 and provided the data necessary to compare site locations recorded prior to, and during the early use of GPS, against the most recently recorded site locations. The analyses of this study are based on 118 previously recorded sites that were revisited and locationally-adjusted during 2014, a process which is discussed in greater detail in Chapter 3.

A high degree of methodical precision is needed to determine exactly how varying GPS technologies may be affecting the characteristics of the aforementioned sites (Wheatley and Gillings 2002). For that purpose, this study will make use of a geographic information system

(GIS) specially designed for collecting, managing, and visualizing the archaeological data investigated by UBARP. This GIS consists of a digital database, geospatial software, and statistical software. Combined, these three components provide the means to efficiently analyze spatial and other relationships among archaeological data that may be highly nuanced or otherwise difficult to detect without computer aid (Conolly and Lake 2006).

Thesis Organization

The contents of this study are organized into six chapters, including this introduction. Chapter 2 presents the survey methodology of UBARP as it has evolved during the last 25 years. For the analytical purposes of this study, I established four broad time periods (described hereafter as GPS Phases) between 1989 and 2014, based on the surveying techniques and capabilities available to UBARP crews during each field season. Only one season of survey work was conducted in any given year, making the task of year-by-year analysis easier to manage. GPS Phase 1 (1989-1993) surveys did not utilize GPS devices, and sites were recorded during this phase using aerial photos and United States Geological Survey (USGS) topographic maps. GPS Phase 2 (1994-1997) survey crews were the first to use GPS, although the technology was very primitive by modern GPS standards, and was restricted by reliance on portable field base stations and Selective Availability (SA). The single survey season of GPS Phase 3 (1999) saw the introduction of a more efficient GPS device and the switch from field to community base stations, although SA was still active. And lastly, GPS Phase 4 (2000-2014) survey crews have made use of continually improving GPS devices without the hindrance of SA. The performance characteristics of each GPS device employed by UBARP, as well as the challenges of operating with SA, are discussed.

Chapter 3 explains in detail the construction and methodology of the GIS used in this study. As mentioned previously, the GIS for this study consists of a database, software for statistical analysis, and software for geospatial analysis. Conveniently, this suite of digital data and software packages is also the default GIS employed by UBARP. Nearly all of the attribute information for every site recorded by UBARP surveyors is stored in the Master Survey Database (MSD), which served as the data source for this thesis. Also in Chapter 3 is a description of the field work conducted in 2014 that provided the comparative samples necessary for this study. In 2014, 328 archaeological sites, or Mapping Units (MUs) (see Chapter 2 for the distinction between "sites" and MUs), that had been recorded in previous years were revisited with a modern GPS device. Of those 328 sites, 118 were found to have poor point coordinates and were rerecorded (see Figure 1.5). This process created measurable adjustment data that could be used in analyzing the spatial performance characteristics of the GPS phases and individual GPS devices. As well, any proclivity that certain survey feature types may have towards spatial distribution and accuracy could be teased out.

The fourth chapter discusses each of the analyses performed in this study. The first analysis examined the mean locational change of the 118 spatially adjusted sites to determine whether GPS phase, GPS device, or survey feature type, had a quantifiable effect on the locational accuracy of sites. Second, I performed a nearest neighbor analysis on site locations prior to, and after adjustment, to see how spatial distribution (tending towards or away from clustering) may have been modified vis-à-vis different GPS phases, GPS devices, and survey feature types. The third analysis compared original and adjusted site locations against environmental and jurisdictional boundaries, as well as elevation and slope. This analysis was designed to reveal how different modes of GPS recording may create unintended variation in the attributes of the archaeological record. Finally, I made graphical observations of the rate at which all sites from throughout UBARP, as well as each individual survey type, were recorded over the last 25 years. This exercise served to illustrate UBARP's dynamic rate of site recording and variability that may be attributable to varying GPS technologies, survey crew sizes, survey season durations, and the primary purposes of each field season.

Chapters 5 and 6 discuss the results of this study and its implications for surveys conducted prior to, and during, the early years of civilian GPS technology. The significance of scale and unit of observation, as they pertain to this study, are elaborated in detail. The results of this study appear to support my hypothesis, that the use of modern GPS technology in archaeological surveys has a positive and quantifiable effect on certain characteristics of the archaeological record. By virtue of this conclusion, inferences drawn from surveys conducted prior to the use of GPS may be worthy of reevaluation.

Chapter 2 – UBARP Survey Methods and Challenges

Beginning in 1989 and continuing into the present, the Upper Basin Archaeological Research Project has been investigating the surface archaeological record of the Upper Basin, Arizona (Magee 2007). This process has entailed both intensive survey over large swathes of the Upper Basin and strategic excavations of particularly diagnostic surface features (Greenberg 2013; Mink 1999; Sullivan et al. 2015). For the purposes of this study, only the survey methods will be covered in detail. The surveying technology available during project seasons has changed dramatically over UBARP's history and it is this variability and its consequences that are of primary importance to this thesis.

To date, 24 km^2 have been systematically surveyed, though this figure underestimates the true total area of the Upper Basin traversed by survey crews, as illustrated by Figure 2.1. Survey crews have made use of various tools to orient themselves, including aerial photographs, topographic maps, compasses, and more recently, GPS navigation devices. Crew members were spaced at 10 m intervals across 40-50 m wide transects (Sullivan and Becher 1991; Szeghi 2012). These transects often originated, terminated at, or were bounded by, conspicuous natural and anthropogenic surface features, such as steep drainage arroyos and roads. Survey orientation was continually monitored via a compass and 'flag line' established at one outer margin of each transect (Sullivan and Becher 1991). This surveying method has remained consistent throughout UBARP's history.

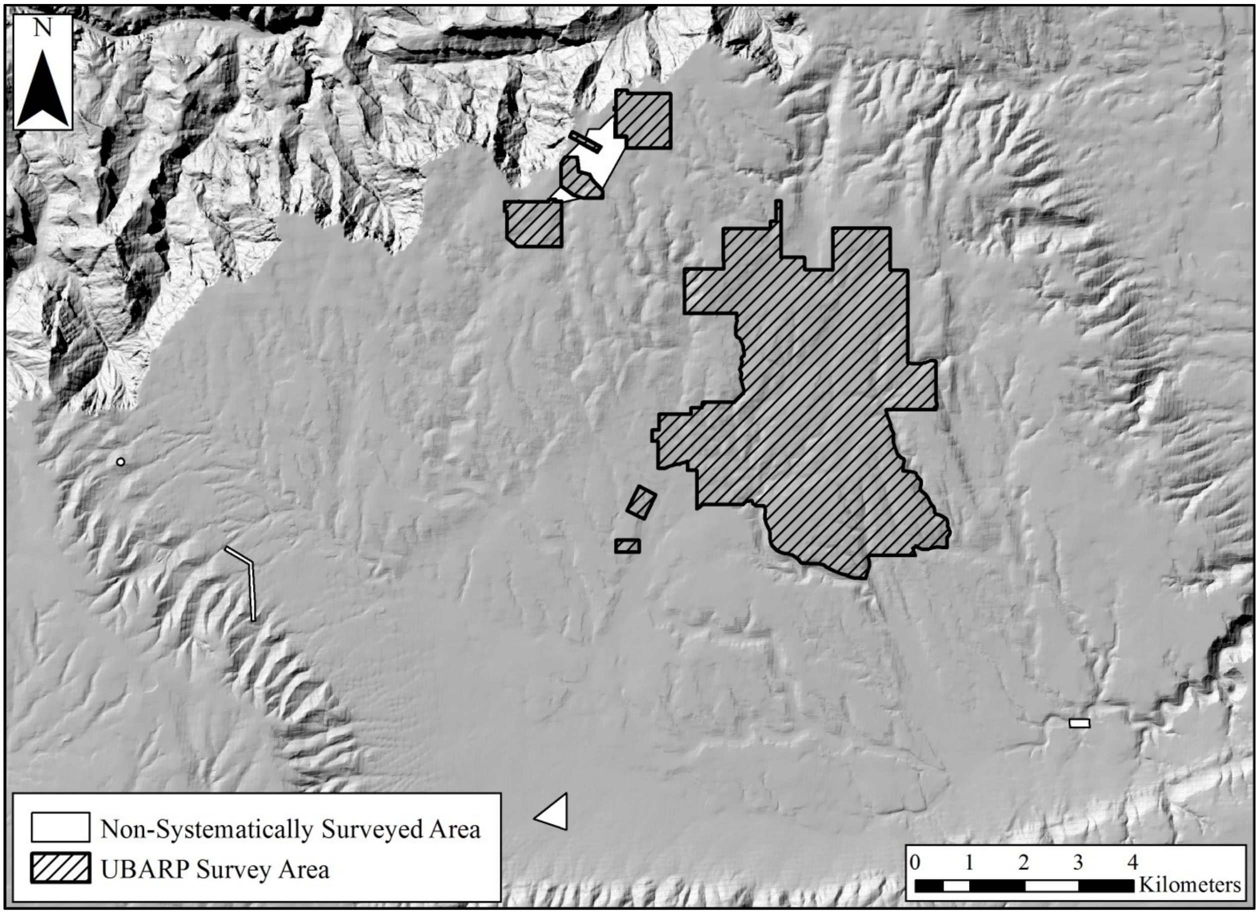


Figure 2.1. UBARP systematically and non-systematically surveyed areas of the Upper Basin.

When an anomalous surface feature or artifact cluster was encountered during the survey crew members would discuss the attributes of the feature and, if it was determined to be of archaeological significance, the feature was recorded and given a Mapping Unit (MU) number (Uphus 2003:9). Mapping Units are categorized by their most prominent feature type, such as masonry structures, lithic scatters, fire-crack-rock piles, alignments, or sweat lodges. The Mapping Unit differs from the traditional 'site' concept in that it more appropriately differentiates surface features spatially based on artifact density and feature discreetness (Sullivan et al. 2007; Szeghi 2012). For example, a large area encompassing three masonry structures and a fire-cracked-rock pile could be designated as a single 'site' for cultural resource management purposes, whereas UBARP might create up to four distinct MUs, each possibly representing various time periods and culture groups despite their spatial proximity (Uphus 2003:9). As Kvamme (1998:128) points out, “Archaeological phenomena generally do not occur in discretely bounded packages about which nice boundaries can be drawn on maps.” The MU concept allows researchers to more robustly analyze and tease apart statistical variation within an archaeological record due to its fine-grained scope (Sullivan 2007; Sullivan et al. 2007).

Survey Phases Defined by Technology

The spatial precision of the Mapping Unit, as utilized by UBARP, has increased over time as more accurate surveying technology has become available to survey crews. For analytical purposes, I have grouped all of UBARP’s project seasons into four general survey phases, defined by the use, or disuse, of three suites of GPS technology: (1) Pre-GPS period using paper cartography (1989-1993), (2) Earliest GPS period using field base station and active Selective Availability (1994-1997), (3) Middle GPS period using community base stations and active Selective Availability (1999), and (4) Recent GPS period using community base stations without Selective Availability (2000-2014). Aggregating the project seasons into these phases allows the researcher to more effectively understand and appreciate the spatial differences in the archaeological record produced throughout UBARP’s history. The phases are detailed in the following sections and Table 2.2.

Table 2.2. UBARP GPS Phases and surveying history.

GPS Phase	Year of Field Work	GPS Device	Selective Availability	MUs Established
Phase 1	1989	N/A	N/A	101
	1990			148
	1991			19
	1992			67
	1993			17
Phase 2	1994	Trimble Pathfinder Basic+	Active	15
	1995			45
	1996			3
	1997			34
Phase 3	1999	Trimble GeoExplorer II/III		253
Phase 4	2000		Inactive	125
	2001			118
	2002			156
	2003			107
	2006	Trimble GeoExplorer 2005		173
	2007			310
	2008			271
	2009			50
	2010			49
	2012			126
	2014	Trimble GeoXH 6000		71

Phase 1: Pre-GPS Paper Cartography (1989-1993)

In the earliest project seasons (1989, 1990, 1991, 1992, and 1993) survey crews used aerial photographs to mark the locations of MUs, which were then transferred to a USGS topographic map (Figure 2.3). The Pythagorean method of triangulation was used to derive UTM coordinates for each MU from the map. At best, this process could only reasonably gauge a MU’s location within approximately 50 meters. This severely limited the researchers’ ability to differentiate any archaeological features or clusters smaller in size than the topographic map could feasibly represent. For this reason, the earliest MUs were often multi-component archaeological sites that covered large surface areas (see Figure 2.4 for an example). Over 600 MUs representing 16 survey feature types were established during this period: lithic scatters (n=178), masonry structures (n=153), and sherd & lithic scatters (n=89) being the most common.

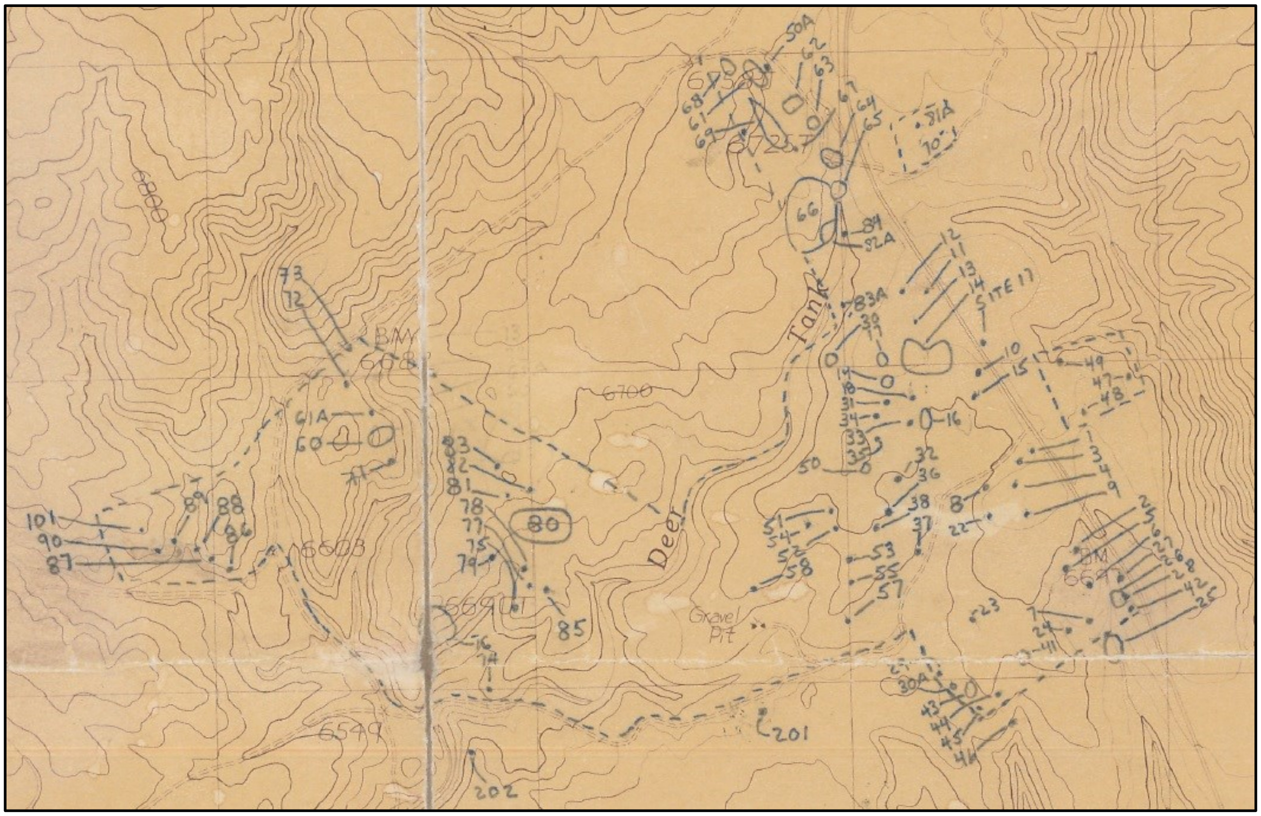


Figure 2.3. Topographic map used to locate coordinates for MUs established in 1989.

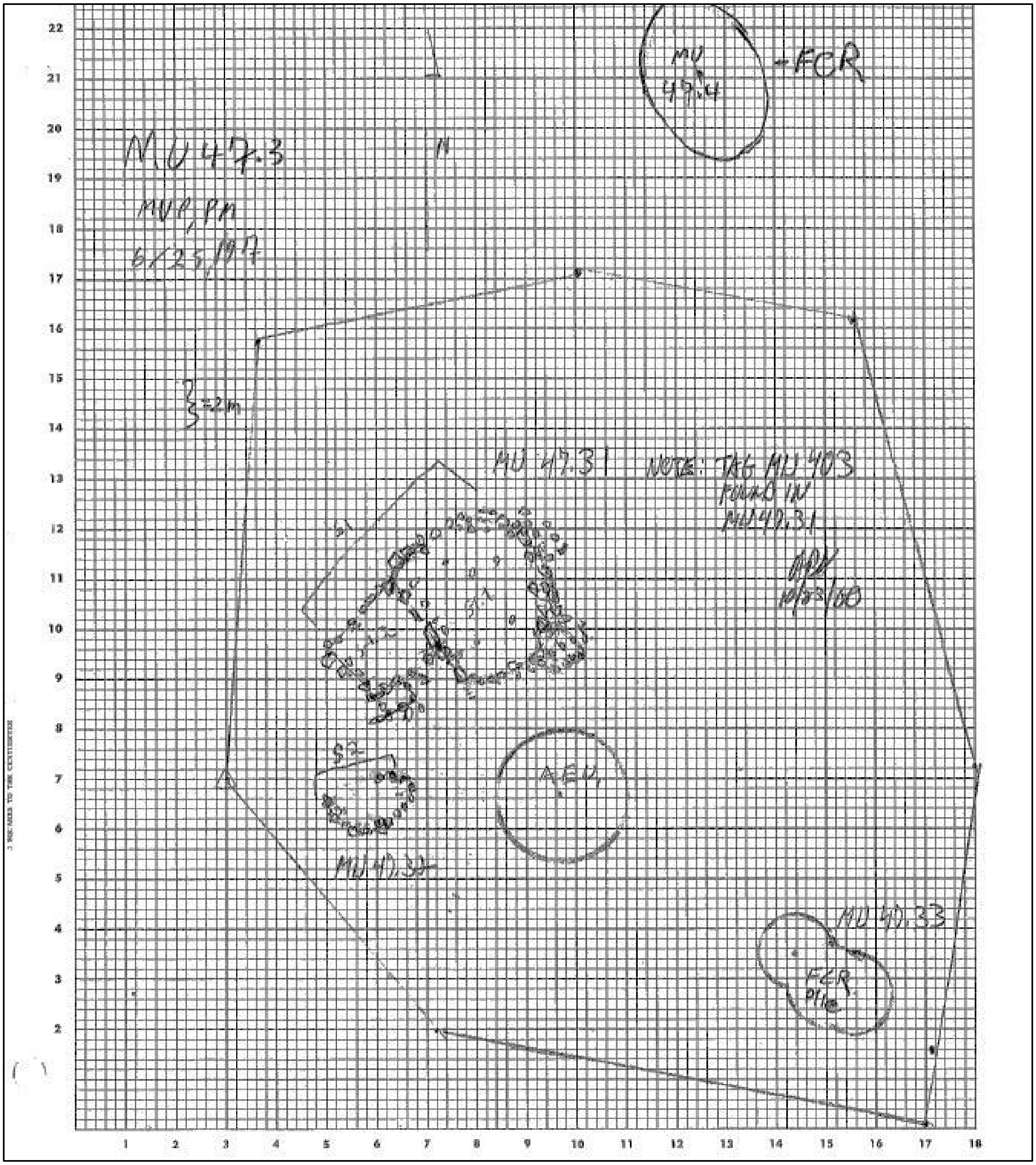


Figure 2.4. MU 47.3 initially encompassed every feature within the polygon and was later disaggregated into three separate MUs.

Phase 2: GPS Field Base Station with Active Selective Availability (1994-1997)

In 1994, UBARP acquired an early model commercial GPS device to aid in the process of surveying and locating the coordinates of MUs directly in the field. The GPS equipment consisted of a handheld rover and a field base station receiver for differential correction. The process of differential correction requires a fixed location, such as a base station with known coordinates (Puterski et al. 1992). Throughout the course of a day, the station's receiver logs its location, which "shifts" a small amount at any given point in time, according to the GPS satellite constellation overhead and other atmospheric scattering factors (Fitts 2005:182). The "shift," or difference between where the base station actually is on the ground and where the satellites believe it to be is the correction factor, which can then be applied to any points taken by a nearby rover at that specific time (Howard 2007). In this way, differentially corrected coordinates are more spatially accurate than those that are uncorrected (Barrat et al. 2000:134; Conolly and Lake 2006:63).

The field base station used during the 1994-1997 seasons—Phase 2 in this study—was not without technical drawbacks. Each day of field work the station was set up on a known benchmark location and left running while the survey crews traversed the local area. It was not uncommon to return at the end of the day to find the base station had been knocked over by wildlife or had shut off inadvertently. These setbacks hampered the reliability of any data collected during that day, and ultimately hindered the overall efficiency of those project seasons.

Of further concern for spatial accuracy during this period was the intentional offsetting of GPS coordinates by the federally enacted policy of Selective Availability. This program purposefully degraded GPS satellite time signals, creating errors of up to 100 meters in ground rovers (Howard 2007:74). The policy was designed as a national defense measure to inhibit hostile missile and ordnance accuracy, though public and commercial users of the American GPS satellite constellation across the globe invariably suffered alongside. Selective Availability was effectively deactivated in May of 2000 by presidential executive order, affording commercial GPS users a confidence boost in their devices, reducing ground accuracy errors from 100m to 12m or less (Fitts 2005:182). The reliability of any coordinates of archaeological phenomena obtained by UBARP prior to 2000 is, therefore, under heavy scrutiny because of the scattering effects of Selective Availability. The need to ground-truth and secure more accurate spatial data for these earlier MU locations, 28 of which were found during Phase 2, has inspired several recent project seasons of UBARP.

Phase 3: GPS Community Base Stations with Active Selective Availability (1999)

After 1997, community base stations became available for use by the general public throughout the American Southwest (Snay and Soler 2008). This access to consistent stations for differential correction made setting up a field base station for every day of field work obsolete. As a result, the spatial data collected and corrected from the 1999 project season—Phase 3—was less susceptible to the whims of curious creatures and unreliable battery life. The full effects of Selective Availability were still active, however, during this time (Puterski 1992). There were 133 Mapping Units recorded during this period.

Phase 4: GPS Community Base Stations (post 1999)

Since 2000, the survey crews of UBARP have had access to increasingly more reliable GPS rovers and community base stations, as well as freedom from Selective Availability. This most recent period, Survey Phase 4, encompasses 11 project seasons from 2000 to the present, and has recorded 1,503 Mapping Units. Several of these project seasons, as mentioned previously, have been devoted less to surveying new areas, and more to ground-truthing the accuracy of earlier locations for the benefit of improving spatial reliability for the UBARP survey database. The confidence in ensuring that the most recent GPS coordinates are accurate is high given that, with differential correction, sub-meter accuracy can be achieved by today's professional GPS devices (Shi and Qiao 2012).

Chapter 3 – GIS Methodology of the Study

This study principally concerns the effects that changes in geospatial technologies have on the characteristics of the archaeological record. As such, a comprehensive geographic information system (GIS) is necessary to fully appreciate and analyze the quantitative properties inherent in spatial archaeological patterns (McCoy and Ladefoged 2009; Wheatley and Gillings 2002). For the purposes of defining the GIS used in this study, I refer to Kvamme (1999:154), who asserts that a "GIS can be regarded as an information visualization engine, but one with extensive analysis, data generation, and manipulative capabilities." It should be noted, however, that because the potential uses for which a GIS may be designed are myriad, the number of precise definitions for what constitutes a GIS is legion (Wheatley and Gillings 2002:9).

In order to maintain data consistency between this study and the UBARP database, I have chosen to utilize both Environmental Systems Research Institute's (ESRI) ArcMap 10.2 geospatial software program and IBM's Statistical Package for the Social Sciences 22 (SPSS) program as the foundation for this study's GIS. These software packages work seamlessly together in that the former visualizes and spatially analyzes the statistically relevant attributes in the latter's database format. Therefore, at the most fundamental level, this GIS is comprised of a database of archaeological features which contains many attribute data and a mapping program to represent spatial relationships between those data (Conolly and Lake 2006:15; see Figure 3.1). The database used in this study is exactly the same as is used by UBARP, and its creation and development are explained in further detail below. Although the ArcMap software is also utilized by UBARP, the maps and derived spatiotemporal analyses are an exclusive product of this study.

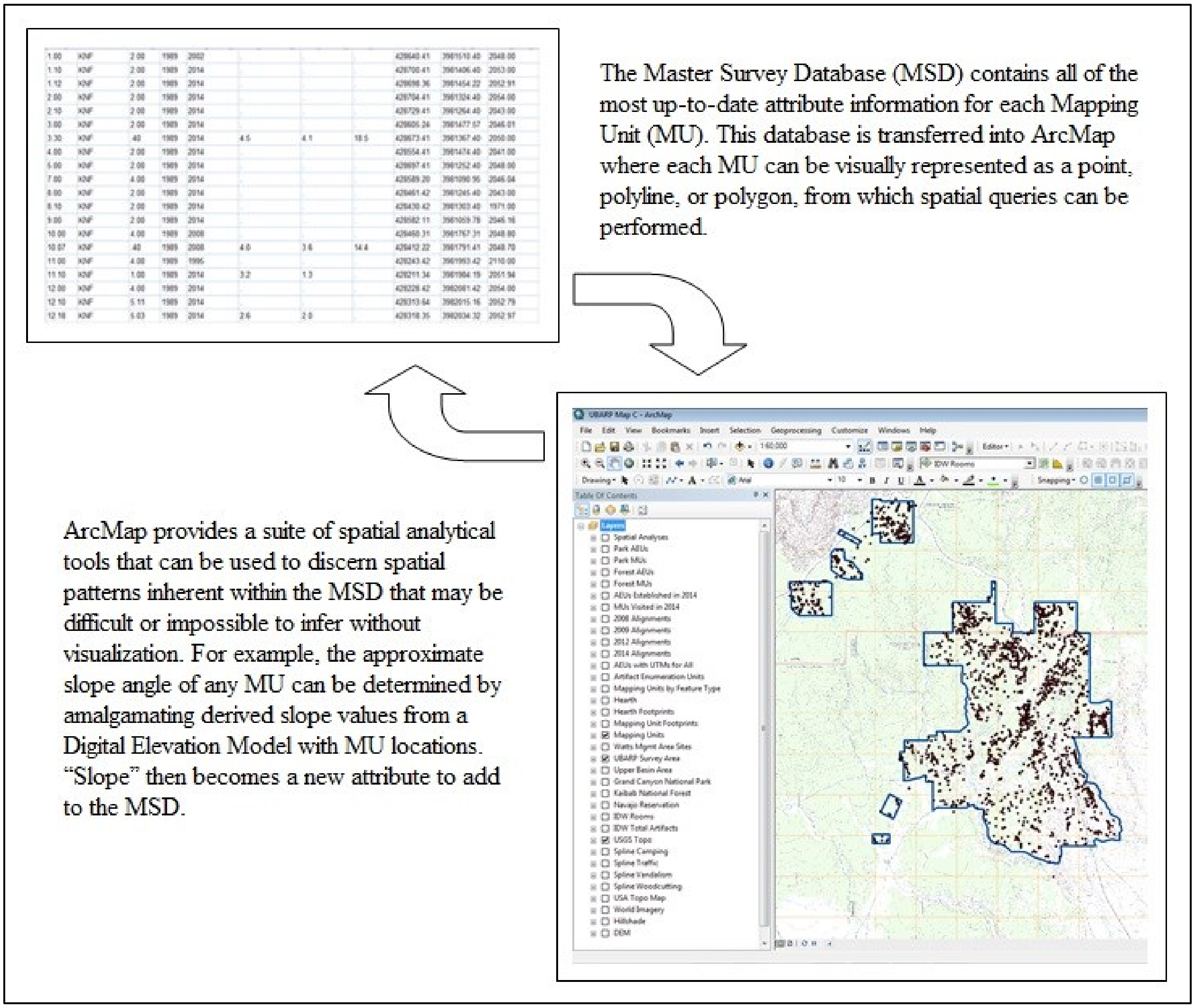
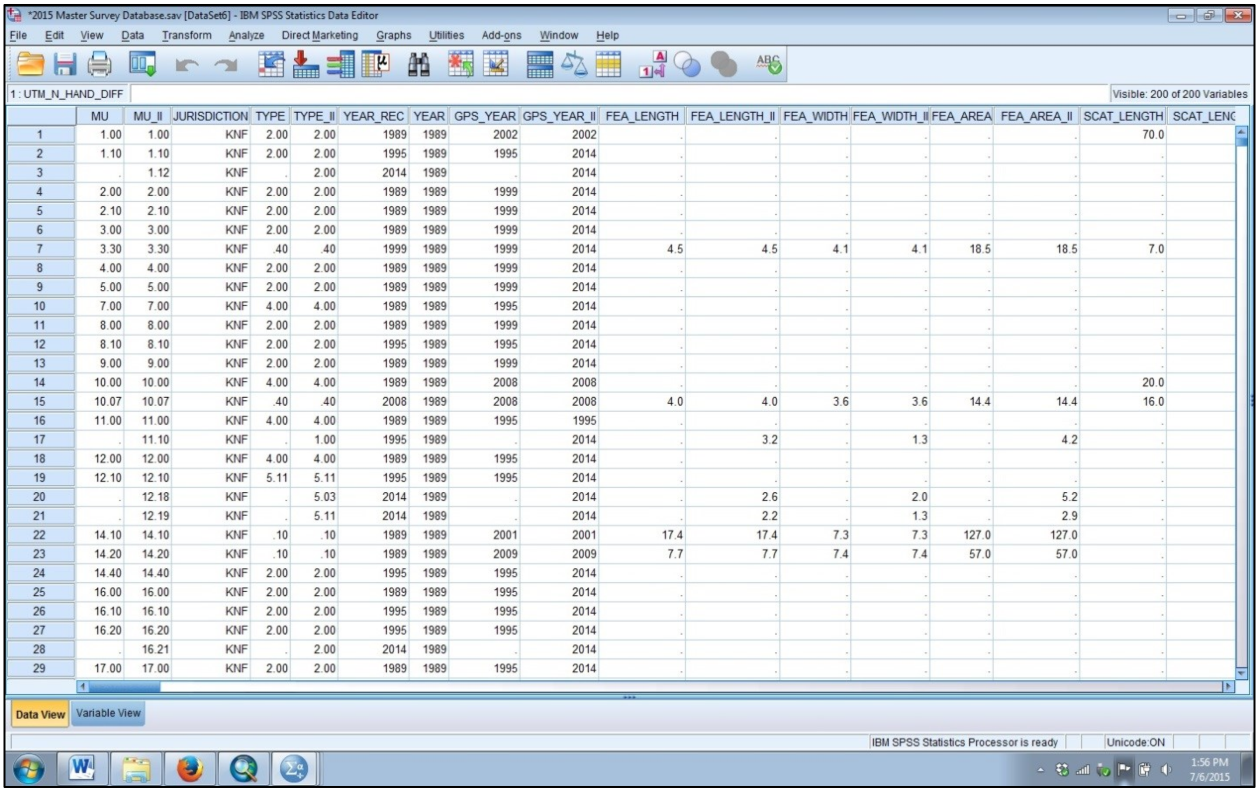


Figure 3.1. Data exchange between Master Survey Database and ArcMap.

Master Survey Database

Several unique databases have been created as a result of 21 UBARP fieldwork seasons. These databases are primarily collections of Mapping Unit (MU) data that have been continually modified during the last 25 years, and reflect the changing needs and observations of researchers throughout the course of UBARP. At the conclusion of each season, a new Master Survey Database (MSD) is established to serve as the central repository for all accumulated MU data up to that point, and is labeled by the year of creation. Thus, there are numerous existing versions of the MSD from previous years. For this study, I make use of the most up-to-date 2015 MSD, and several from previous seasons to critically compare changes in site type representation and spatial patterns across time, a process which is detailed in Chapter 4.

The 2015 MSD includes the full breadth of quantitative information known for each currently existing MU in UBARP. Fundamentally, the MSD provides the feature type and locational data (Universal Transverse Mercator [UTM] easting and northing coordinates) for each MU. In addition, most of the MUs within the MSD contain other statistically significant information, such as year of discovery, most recent GPS year, feature measurements, elevation, environmental attributes, and artifact types present, among others. Because of the multitude of information present, the MSD allows a researcher to explore a variety of facets of UBARP's archaeological record: from site and artifact densities, to mean lithic scatter elevation, to the extent of vehicular disturbance, and beyond. As concerns this study, the most important attributes in the MSD are Feature Type, Year of Discovery, Most Recent GPS Year, UTM Easting, and UTM Northing (see Table 3.2). It is worth noting that UBARP's designation of MU attributes has increased over time and recent MSDs contain more auxiliary attribute data than those of earlier years. The attribute data used in this study have been gathered in every field season since UBARP began, however, enabling unabridged cross-temporal analyses.



	MU	MU_II	JURISDICTION	TYPE	TYPE_II	YEAR_REC	YEAR	GPS_YEAR	GPS_YEAR_II	FEA_LENGTH	FEA_LENGTH_II	FEA_WIDTH	FEA_WIDTH_II	FEA_AREA	FEA_AREA_II	SCAT_LENGTH	SCAT_LENG
1	1.00	1.00	KNF	2.00	2.00	1989	1989	2002	2002	.	.	.	.	.	.	70.0	
2	1.10	1.10	KNF	2.00	2.00	1995	1989	1995	2014	.	.	.	.	.	.	.	
3	.	1.12	KNF	.	2.00	2014	1989	.	2014	.	.	.	.	.	.	.	
4	2.00	2.00	KNF	2.00	2.00	1989	1989	1999	2014	.	.	.	.	.	.	.	
5	2.10	2.10	KNF	2.00	2.00	1989	1989	1999	2014	.	.	.	.	.	.	.	
6	3.00	3.00	KNF	2.00	2.00	1989	1989	1999	2014	.	.	.	.	.	.	.	
7	3.30	3.30	KNF	.40	.40	1999	1989	1999	2014	4.5	4.5	4.1	4.1	18.5	18.5	7.0	
8	4.00	4.00	KNF	2.00	2.00	1989	1989	1999	2014	.	.	.	.	.	.	.	
9	5.00	5.00	KNF	2.00	2.00	1989	1989	1999	2014	.	.	.	.	.	.	.	
10	7.00	7.00	KNF	4.00	4.00	1989	1989	1995	2014	.	.	.	.	.	.	.	
11	8.00	8.00	KNF	2.00	2.00	1989	1989	1999	2014	.	.	.	.	.	.	.	
12	8.10	8.10	KNF	2.00	2.00	1995	1989	1995	2014	.	.	.	.	.	.	.	
13	9.00	9.00	KNF	2.00	2.00	1989	1989	1999	2014	.	.	.	.	.	.	.	
14	10.00	10.00	KNF	4.00	4.00	1989	1989	2008	2008	.	.	.	.	.	.	20.0	
15	10.07	10.07	KNF	.40	.40	2008	1989	2008	2008	4.0	4.0	3.6	3.6	14.4	14.4	16.0	
16	11.00	11.00	KNF	4.00	4.00	1989	1989	1995	1995	.	.	.	.	.	.	.	
17	.	11.10	KNF	.	1.00	1995	1989	.	2014	.	3.2	.	1.3	.	4.2	.	
18	12.00	12.00	KNF	4.00	4.00	1989	1989	1995	2014	.	.	.	.	.	.	.	
19	12.10	12.10	KNF	5.11	5.11	1995	1989	1995	2014	.	.	.	.	.	.	.	
20	.	12.18	KNF	.	5.03	2014	1989	.	2014	.	2.6	.	2.0	.	5.2	.	
21	.	12.19	KNF	.	5.11	2014	1989	.	2014	.	2.2	.	1.3	.	2.9	.	
22	14.10	14.10	KNF	.10	.10	1989	1989	2001	2001	17.4	17.4	7.3	7.3	127.0	127.0	.	
23	14.20	14.20	KNF	.10	.10	1989	1989	2009	2009	7.7	7.7	7.4	7.4	57.0	57.0	.	
24	14.40	14.40	KNF	2.00	2.00	1995	1989	1995	2014	.	.	.	.	.	.	.	
25	16.00	16.00	KNF	2.00	2.00	1989	1989	1995	2014	.	.	.	.	.	.	.	
26	16.10	16.10	KNF	2.00	2.00	1995	1989	1995	2014	.	.	.	.	.	.	.	
27	16.20	16.20	KNF	2.00	2.00	1995	1989	1995	2014	.	.	.	.	.	.	.	
28	.	16.21	KNF	.	2.00	2014	1989	.	2014	.	.	.	.	.	.	.	
29	17.00	17.00	KNF	2.00	2.00	1989	1989	1995	2014	.	.	.	.	.	.	.	

Figure 3.2. Example of the 2015 Master Survey Database (in SPSS) used in this study: columns represent Mapping Unit attributes, rows (cases) represent individual Mapping Units.

GIS Survey Database Integrity

Any project that involves data collection, organization, and interpretation, no matter the scope or intent, invariably has a human element involved at one or more steps in the process (Woods et al. 2010). The archaeological fieldwork conducted by UBARP during the last 25 years is no exception to this rule. As such, the 2015 MSD is only as reliable a product as both human fallibility and data transformational error will allow (Woods et al. 2010:145). It is especially crucial to recognize and address this condition for the sake of this study because of the incalculable amount of human effort spent in gathering and organizing UBARP's data with multiple GPS and PC platforms over the course of a quarter century (Ortman et al. 2007). The MSD created—or, more accurately, re-created—at the conclusion of each survey season, and the primary analytical source for this study, is the direct result of a complex series of these humantechnological interactions, the inherent hazards of which are explained in the following paragraphs (Woods et al. 2010).

As covered in the previous chapter, initial archaeological data collection for UBARP has involved intensive surveys and the establishment of MUs at features of archaeological interest. These MUs have, at their core, the fundamental attributes mentioned above (Feature Type, Year of Discovery, Most Recent GPS Year, UTM Easting, UTM Northing, and Elevation), recorded in Phase 1 without GPS technology, and recorded in subsequent phases with increasingly more accurate GPS technology. The first point of entry for human error begins at this stage, where the data for a Mapping Unit are either handwritten or entered into a GPS device, the latter of which presents a host of challenges for the user (see Chapter 2).

The earliest MU attributes were recorded in field notebooks by one or more recorders each field season (Phase 1). Transferring these paper notes into a database entailed the potential for routine human errors such as mislabeling, entering data into incorrect columns, introducing human fatigue into the operation, etc. Once GPS technology became available to UBARP (Phases 2 and later), the data collected in the field became digital and required special software to migrate from device to database. This digitization of the recording process added a heretofore unknown step that survey crews had to overcome in order to properly collect data, often without any practice beforehand (Table 3.3) (Fitts 2005:187). Correct operation of a GPS device does not come as second nature to all surveyors, and the opportunity to incorrectly enter data into the device or poorly record a MU's location can vary considerably between survey crewmembers (see Table 3.4 for a non-exhaustive list of potential perils in using GPS).

Once MU information collected in the field went digital, it necessitated special handling in order to migrate into the MSD. Converting the data collected with a GPS device to a database is, although far more automated, also less transparent to the user, and requires more steps than manual data entry to ensure correct data transference (Conolly and Lake 2006:61). GPS rovers used by UBARP collect their data in the form of rover files, which are read exclusively by GPS-capable devices and software (Hurn 1989). A software program called GPS Pathfinder, produced by Trimble, was used to import rover files into a computer (Uphus 2003:12). These files were then exported into a variety of useful file formats, such as ESRI shapefiles (.shp), Microsoft Excel files (.xlsx), and database files (.dbf). Once exported, these data were added into the most recent MSD, thus expanding upon the data gathered in previous field seasons. At any time during this data conversion process human error could have occurred at one or more steps resulting in data being misapplied in the database, lost or left out from conversion, doubled or repeated, etc. (see Table 3.4).

Table 3.3. GPS devices used by UBARP and their associated performance characteristics.

GPS Device	GPS Phase (Years)	Spatial Accuracy*	Device Pros	Device Cons
Trimble Pathfinder Basic+	2 (1994-1997)	~11m[1]	--	Multi-component (receiver, battery pack, antenna, cables), very limited user interface
Trimble GeoExplorer II	3-4 (1999-2003)	2-5m[2]	Single component	Limited user interface
Trimble GeoExplorer 2005	4 (2006-2012)	<1m[3]	Single component, improved user interface	--
Trimble GeoXH 6000	4 (2014)	~10cm[4]	Single component, user-friendly interface	--

* Estimated spatial accuracy for differentially-corrected points recorded over 30 seconds.
[1]derived from this study; [2] GeoExplorer II Operation Manual (1996); [3] Getting Started Guide: GeoExplorer 2005 Series (2005); [4] User Guide: GeoExplorer 6000 Series (2011)

Table 3.4. Potential data errors encountered between the first step of Mapping Unit (MU) establishment and the last step of data entry into the Master Survey Database (MSD) when using a GPS device during survey.

Error	Data Processing Step	End Effect
Surveyor(s) provide GPS user with incorrect MU measurements, attributes	Data Collection	If unchecked against written notes, MSD contains inaccurate MU attribute information
GPS user incorrectly enters MU attributes into device	Data Collection	If unchecked against written notes, MSD contains inaccurate MU attributes
GPS user fails to take a sufficient number of positional points	Data Collection	Actual MU location may be several meters distant from GPS location
GPS user "wanders" with the device actively taking positional points	Data Collection	Actual MU location may be several meters distant from GPS location, and line and polygon features may be misrepresented in shape and size
Selective Availability (Phases 2-3) skews GPS satellite signals	Data Collection	Actual MU location may be up to 100 meters distant from GPS location
GPS points taken during poor satellite communication periods	Data Collection	MU location may fail to record in GPS device, or may be several meters distant from GPS location
User fails to import all rover files from device into Pathfinder software	Data Processing	If unchecked against written notes, MUs will be missing from MSD
User fails to differentially correct rover files	Data Processing	If uncorrected rover files are used, actual MU locations may be several meters distant from GPS locations
User selects low integrity base station (i.e., too distant) for differential correction	Data Processing	Actual MU location may be several meters distant from GPS location, or may fail to differentially correct
User exports incorrect or partially correct MU data from Pathfinder software into MSD	Data Entry	MSD contains inaccurate MU attribute information
User manually enters incorrect data from a different format (.xlsx, .dbf) into MSD	Data Entry	MSD contains inaccurate MU attribute information

Data Remediation and Locational Ground-Truthing

Given the potential for error that may have been introduced at any point between data recording in the field and data addition to the MSD in UBARP's 25 year history, the need for ensuring data reliability has been of paramount importance to UBARP's researchers. As well, the spatial and temporal analyses conducted in pursuit of this study are contingent upon the accuracy and integrity of the MSD. For these reasons, a number of UBARP researchers over the past decade—myself included—have checked and refined the data within the most current MSD against survey notes to eliminate or replace erroneous data and fill in missing gaps. Also, several survey crews from previous field seasons devoted some of their time in the field to revisiting MUs from UBARP's early years and improving their locational and attributional records. The most recent season (Fall 2014) was dedicated almost entirely to the pursuit of ground-truthing over 400 MUs to improve the accuracy of their coordinate information, an effort prompted in part by this study.

The spatial nature of this study demands a close inspection of the locations of all 2,262 MUs established so far by UBARP. For this reason, I proposed a quasi-survey project to revisit and, if necessary, take new GPS locations at 422 MUs that had last been visited with GPS prior to 2000, when Selective Availability (see Chapter 2) was still active and the GPS technology employed by UBARP was crude by today's standards. To this end, between October 18 and November 3, 2014, a crew of four archaeological surveyors (including myself) successfully relocated 328 MUs, of which 118 were spatially adjusted (new GPS points were taken), 30 were reclassified into different feature types, and 16 were decommissioned on account of their vague or obliterated nature (see Figure 3.5). Coincidentally, 70 new MUs were established at previously unrecorded archaeological phenomena. The discovery of this many new MUs is interesting because the majority of the areas of the Upper Basin traversed on foot in 2014 had already been surveyed intensively one or more times in the past. The discovery of these new MUs provides further data for UBARP survey database, a boon that had not been expected at the project's outlay.

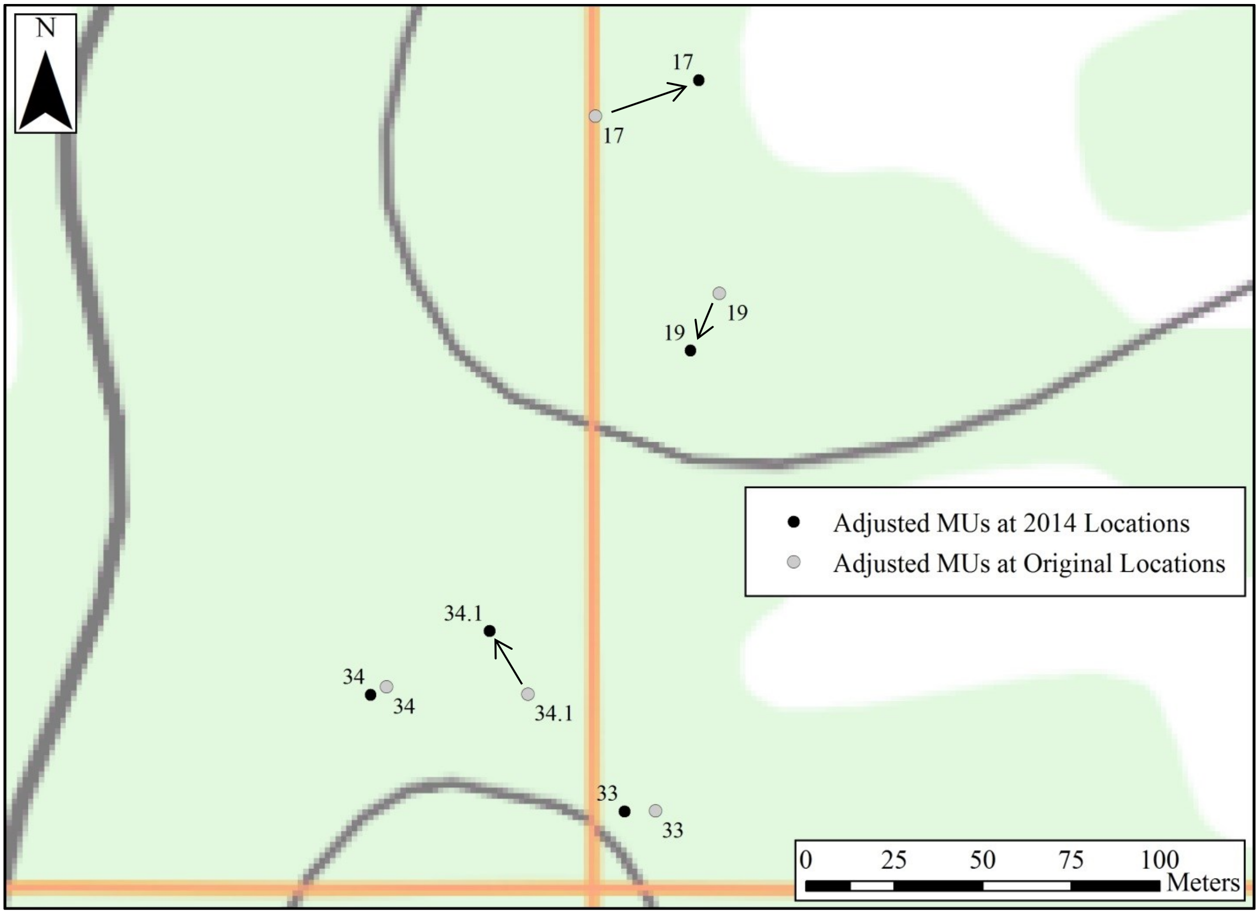


Figure 3.5. Example of 2014 ground-truthing adjustment results.

Chapter 4 – GIS Analysis of Mapping Unit Locations

In order to determine if different mapping technologies have affected the spatial characteristics of archaeological phenomena, certain statistical, spatial, and temporal analyses are needed (Conolly and Lake 2006; Greenberg 2013:6). For this study, I have chosen to use the following tests: mean locational change, nearest neighbor analysis, and locational attribute querying. These tests are designed to discover minor changes in the locational positions of Mapping Units (MUs) within the data-rich Master Survey Database (MSD), as well as reveal interpretive biases in the data that may have remained unscrutinized without consideration for the mapping process itself (Aldenderfer 2010:56). As well, an observation is made of the annual MU discovery rate to discern the effects that survey crew size, survey duration, field season purpose, and evolving GPS technology have had on the rate.

Mean Locational Change Analysis

As stated in previous chapters, the Upper Basin Archaeological Research Project (UBARP) has employed a variety of non-GPS and GPS techniques for mapping the locations of MUs. The first test proposed above, mean locational change, provides a means to measure the proportional changes in positional accuracy between each of the GPS phases (VanPool and Leonard 2011). It is a fundamental assumption of this study that MU locations secured through the most recent of GPS Phase 4 differentially-corrected GPS technology in the 2014 field season are the most accurate in terms of proximity to actual ground locations. With this assumption, I can arguably compare the old and current GPS locations of those MUs that were spatially adjusted in 2014. The mean locational change between GPS Phases, between individual GPS years, and between feature types may reveal statistically significant impacts that different GPS technologies have had on the positional characteristics of the archaeological record (Wheatley and Gillings 2002:147).

Using the tools within SPSS (see Chapter 3), it is possible to derive the mean values for locational changes of the 118 MUs that were spatially adjusted during field work in 2014. The locations of adjusted MUs that were previously recorded during each phase were compared against their 2014 GPS locations. The results of this test are displayed in Table 4.1. Not surprisingly, these data trend towards increased spatial accuracy the closer their temporal proximity to 2014.

Table 4.1. Average locational adjustment (meters) between previous MU locations and 2014 locations per GPS phase.

GPS Phase	Year(s)	# MUs	Mean Change	Median	Max	Std. Dev.
1	1989-1993	28	150.53	69.56	1688.38	313.39
2	1994-1997	42	12.87	11.10	35.08	8.92
3	1999	64	5.89	2.71	69.50	10.10
4	2000-2012	12	2.44	1.76	6.74	1.95

It is worth mentioning that 212 MUs in the 2015 MSD contain hand-plotted UTM coordinates from Phase 1. Because they are not GPS-based, these locations (and their adjustments to 2014 values) help to demonstrate the dramatic variation in spatial accuracy from the earliest years of UBARP to the present. Of the 118 MUs adjusted in 2014, 28 have hand-plotted locations. When compared against their 2014 locations, these MUs have a mean locational change of 150.53 m, a maximum of 1,688.38 m, and a standard deviation of 313.39 m. The exceedingly high maximum value for this phase’s test is illustrative of the hazards involved in interpreting data through paper maps and manual methods, as described in Chapter 3 (Burger and Todd 2006; Mink et al. 2006:220).

The next mean locational change test compared MU locations from individual years, rather than grouped in phases, against their 2014 locations. It is possible, with this test, to detect more minute changes in spatial accuracy across time than is feasible with the phase-based test.

The 118 adjusted MUs represent GPS locations recorded from eight different field seasons, 1995-2012. There are considerably fewer recent MUs (2003-2012) adjusted, as the field work in 2014 was designed to ground-truth earlier MU locations. The paucity of adjustment data for these later MU recordings should be kept in mind when reviewing the results of this test. Similar to the phase-based test, these results demonstrate a positive correlation between time and spatial accuracy (Table A.1).

The final mean locational change test was designed to provide data regarding the likelihood that feature types themselves may have played a deterministic part in GPS spatial accuracy. As with the previous two tests, MU locations of individual feature types were compared against their locations recorded in 2014. This test is, by its nature, somewhat convoluted in its appraisal of causality because it fails to distinguish the effects of any cross-temporal changes in GPS technology. Therefore, this test serves only to illustrate how feature types may affect spatial accuracy. It was an initial assumption of this study that lithic scatters and sherd & lithic scatters would have been adjusted the most by virtue of their broad scale on the landscape and imprecise central locations. Aside from one extraordinarily adjusted wood hogan (MU 313.12), the scatters did prove to be the least spatially accurate feature types (Table A.2). This result speaks to the importance of defining surficial archaeological phenomena as discretely as possible (Conolly and Lake 2006:29; Sullivan et al. 2007:326).

Nearest Neighbor Analysis

The second test, nearest neighbor analysis, offers a measure of relative locational change that differs from the mean locational change analysis in its methods and purpose. Whereas the previous tests magnified locational changes in an absolute, Euclidean manner, nearest neighbor analysis determines relative changes in point distribution, specifically, trends towards clustering or dispersal (Conolly and Lake 2006:4). Using nearest neighbor, I can tease out the effects that different GPS technologies may have had on the broader landscape scale (Kvamme 1999:169; Wheatley and Gillings 2002:127). For example, do the locations of MUs recorded in 1999 appear to be more clustered than their counterparts recorded in 2014 (Bevan and Conolly 2006)? As before, the 2014 GPS locations will be used as the comparative benchmark for this analysis.

This test is performed with ArcMap using the Average Nearest Neighbor analysis tool. This tool determines four primary outputs from a layer of surface points: NN Ratio, NN z-score, NN Expected (in meters), and NN Observed (in meters) (ESRI 2013a). NN Expected is the average distance between points in a hypothetical random distribution given the test area and the number of points. NN Observed is the actual average distance between those points. The NN Ratio is an index of the observed-to-expected averages; ratios less than 1 exhibit clustering while a ratio greater than 1 would be indicative of dispersion. NN z-score is a measure of standard deviation from the null hypothesis, which in this case, would be completely random dispersion of points. Z-scores significantly higher or lower than 0 (i.e., ±2.5) express 99% confidence in rejecting the null hypothesis, and demonstrate either a result of clustered (negative) or regular/uniform (positive) patterning. These three potential states of point distribution (random, clustered, or regular) are idealized and highly subject to the scale of the study area, a topic which is covered in the next chapter (Conolly and Lake 2006:162; Burger and Todd 2006:252; Harris 2006:42). For the purposes of this study, the most significant output—and therefore, adjustment factor—is NN Observed, which is the fundamental measure of change for these tests. Tables 4.2, A.3, and A.4 provide the results of these nearest neighbor analyses, which suggest that variation in GPS technology had a near negligible effect on the spatial distribution of these MUs.

Table 4.2. Average nearest neighbor analysis adjustment between previous MU locations and 2014 locations per GPS phase.

GPS Phase	GPS Year(s)	# MUs	NN Ratio	NN Z-Score	NN Expected	NN Observed	Clustering
1	Hand	28	0.914	-0.871	318.68 m	291.26 m	Random
1	2014	28	0.858	-1.434	299.17 m	256.81 m	Random
		Adjustment	**-0.056**	**-0.563**	**-19.51 m**	**-34.45 m**	
2	1995-1997	42	0.666	-4.136	282.38 m	188.17 m	99% Yes
2	2014	42	0.668	-4.115	282.01 m	188.42 m	99% Yes
		Adjustment	**+0.002**	**+0.021**	**-0.37 m**	**+0.25 m**	
3	1999	64	0.499	-7.674	230.93 m	115.15 m	99% Yes
3	2014	64	0.492	-7.780	231.15 m	113.65 m	99% Yes
		Adjustment	**-0.007**	**-0.106**	**+0.22 m**	**+1.5 m**	
4	2003-2012	12	0.923	-0.513	622.38 m	574.23 m	Random
4	2014	12	0.919	-0.536	622.66 m	572.31 m	Random
		Adjustment	**-0.004**	**-0.023**	**+0.28 m**	**-1.92 m**	

Locational Attribute Query

The next test in this analysis is a locational attribute query. Similar to the nearest neighbor analysis, this test is performed with ArcGIS and functions as an additional measure of how variation in MU locations may skew their archaeological characteristics (Wheatley and Gillings 2002:3). This test compares MU locations against a number of other environmental layers on which they are situated in space. For example, do more MUs at their 1995 GPS locations fall within a specific soil type than at their 2014 locations? Soil types are not the only determinant for this test, however. Other layers against which MU locations are compared include elevation, slope, and governmental jurisdiction. Elevation and slope attributes are determined using a digital elevation model (DEM) that underlies the MU layer and represents elevational changes in the landscape (ESRI 2013b) (Figures 4.8 and 4.10). Both governmental jurisdiction (Figure 4.3) and soil types are represented in ArcGIS through layers of interconnected polygons (Figure 4.5). Soil types were established using soil shapefiles from the National Resource Conservation Service and the National Forest Service's Terrestrial Ecosystem

Survey, both of which cover portions of the Upper Basin and the study area (Brewer et al. 1991; NRCS 2015; Winthers et al. 2005).

Each of the attributes examined in this test was analyzed for changes between GPS phases. As in the previous two analyses, I expected changes between GPS years and feature types, in regards to these attributes. However, because the adjustments made across jurisdictional and soil type boundaries were slight, if at all, I omitted testing these attributes against GPS years and feature types. See the tables in this section and Tables A.5—A.8 for the results of this analysis.

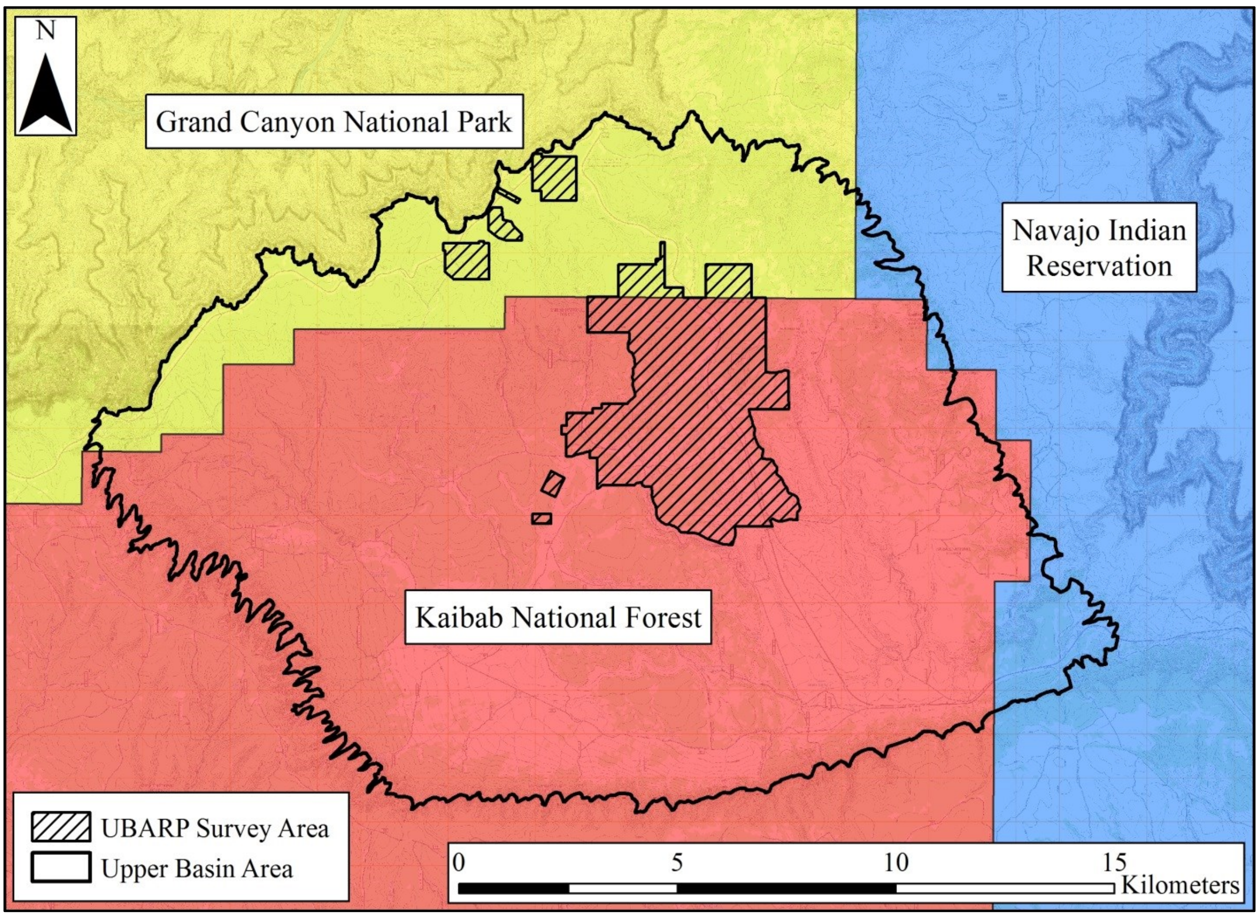


Figure 4.3. Jurisdictional division of the Upper Basin area.

Table 4.4. Adjustments across jurisdictional boundaries between previous MU locations and 2014 locations per GPS phase.

GPS Phase	GPS Year(s)	# MUs	Original MUs in GRCA	Original MUs in KNF
1	Hand	28	0	28
1	2014	28	0	28
		Adjustment	**±0**	**±0**
2	1994-1997	42	0	42
2	2014	42	0	42
		Adjustment	**±0**	**±0**
3	1999	64	0	64
3	2014	64	0	64
		Adjustment	**±0**	**±0**
4	2000-2012	12	7	5
4	2014	12	7	5
		Adjustment	**±0**	**±0**

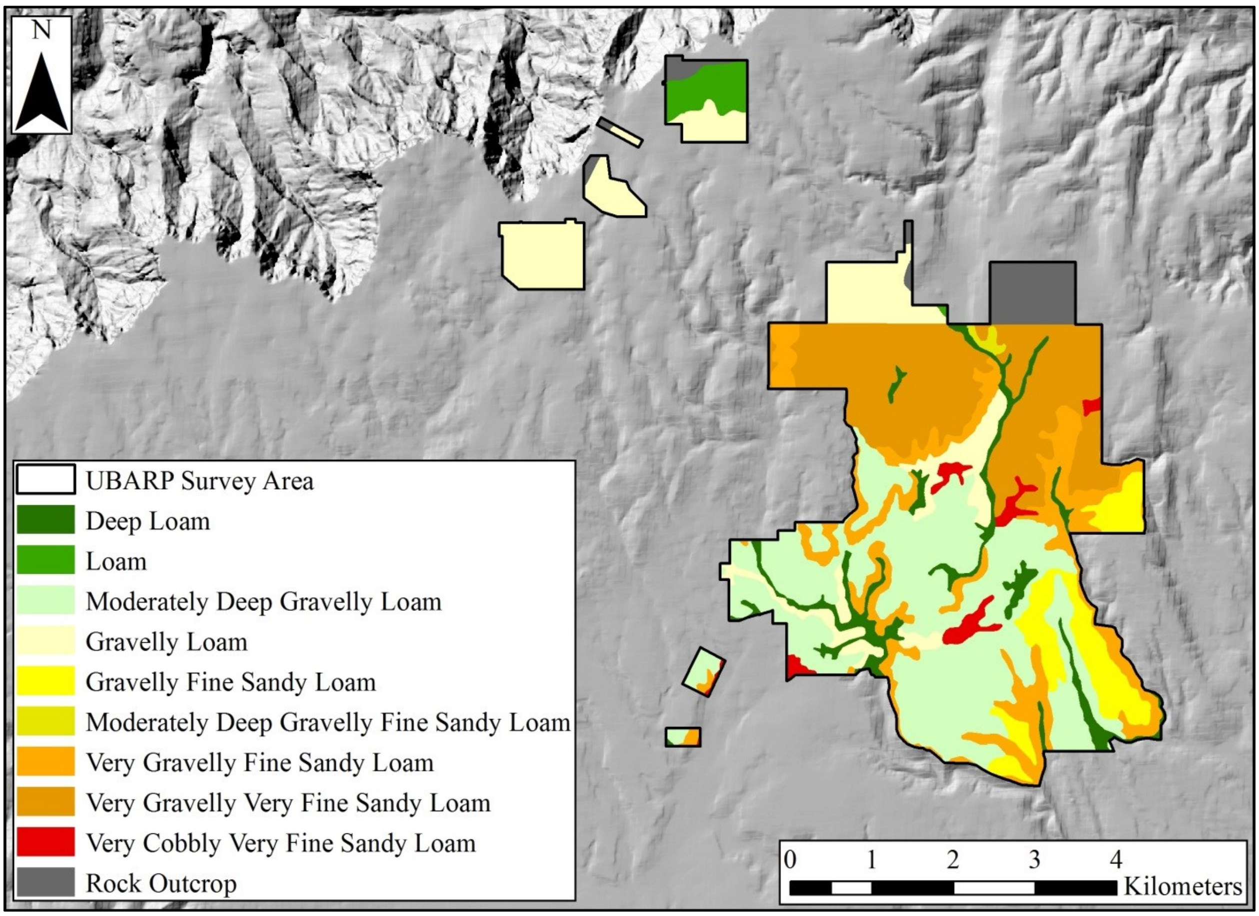


Figure 4.5. Soil phases within UBARP study area.

Table 4.6. Adjustments across soil types between previous MU locations and 2014 locations per GPS Phase (phases 1-2).

GPS Phase Soil Phase	1 (Hand)	1 (2014)	Adjustment	2 (Original)	2 (2014)	Adjustment
Deep Loam	2	1	**-1**	3	4	**+1**
Loam	0	0	**0**	0	0	**0**
Moderately Deep Gravelly Loam	16	17	**+1**	25	25	**0**
Gravelly Loam	1	1	**0**	1	1	**0**
Gravelly Fine Sandy Loam	1	2	**+1**	1	1	**0**
Moderately Deep Gravelly Fine Sandy Loam	0	0	**0**	0	0	**0**
Very Gravelly Fine Sandy Loam	2	2	**0**	2	2	**0**
Very Gravelly Very Fine Sandy Loam	5	4	**-1**	6	6	**0**
Very Cobbly Very Fine Sandy Loam	1	1	**0**	4	3	**-1**
Rock Outcrop	0	0	**0**	0	0	**0**
Total # MUs	**28**	**28**	**±2**	**42**	**42**	**±1**

Table 4.7. Adjustments across soil types between previous MU locations and 2014 locations per GPS Phase (phases 3-4).

GPS Phase Soil Phase	3 (Original)	3 (2014)	Adjustment	4 (Original)	4 (2014)	Adjustment
Deep Loam	3	2	**-1**	0	0	**0**
Loam	0	0	**0**	1	1	**0**
Moderately Deep Gravelly Loam	13	14	**+1**	0	0	**0**
Gravelly Loam	15	15	**0**	5	5	**0**
Gravelly Fine Sandy Loam	7	7	**0**	2	2	**0**
Moderately Deep Gravelly Fine Sandy Loam	0	0	**0**	0	0	**0**
Very Gravelly Fine Sandy Loam	3	3	**0**	1	1	**0**
Very Gravelly Very Fine Sandy Loam	23	23	**0**	2	2	**0**
Very Cobbly Very Fine Sandy Loam	0	0	**0**	0	0	**0**
Rock Outcrop	0	0	**0**	1	1	**0**
# MUs	**64**	**64**	**±1**	**12**	**12**	**±0**

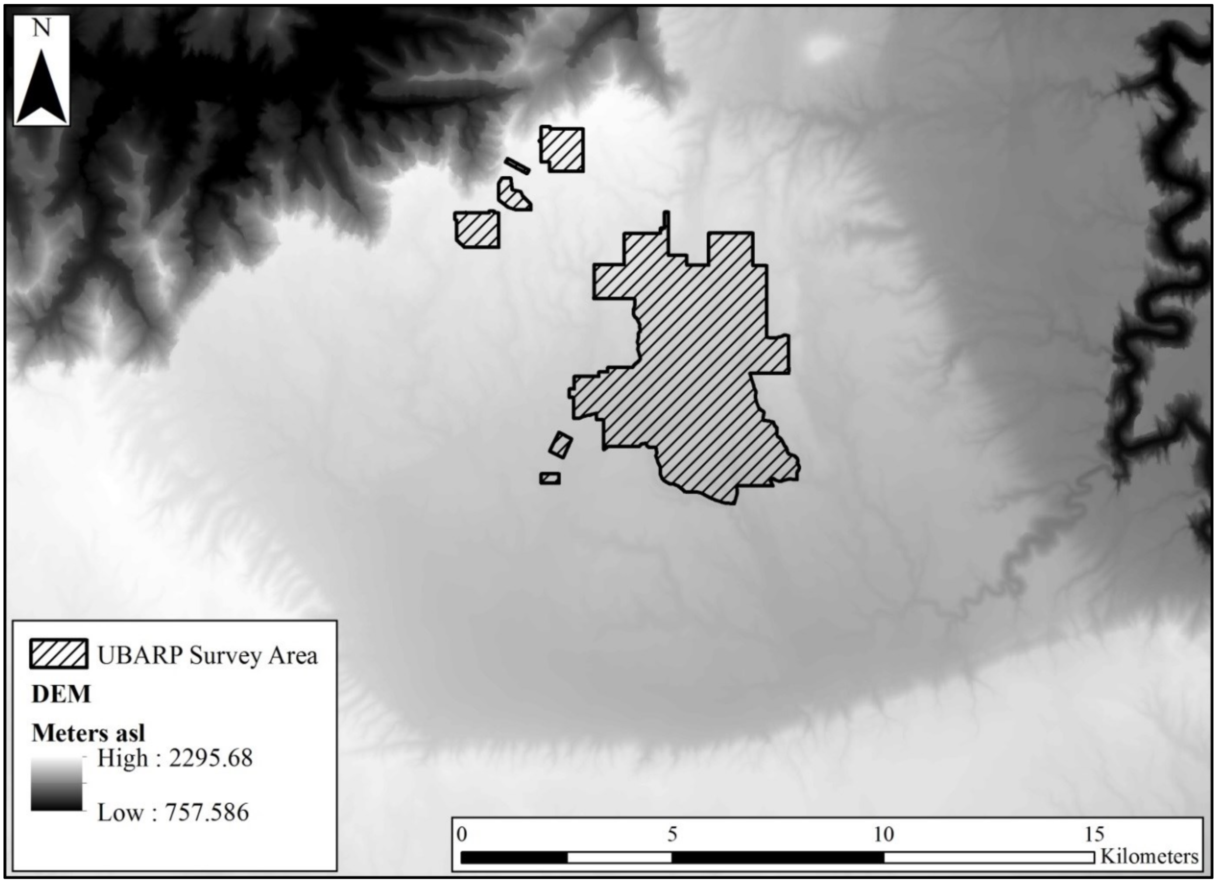


Figure 4.8. 10 meter Digital Elevation Model of the Upper Basin area

Table 4.9. Average elevation adjustment between previous MU locations and 2014 locations per GPS phase.

GPS Phase	GPS Year(s)	# MUs	Mean Elevation	Median Elevation	Min. Elevation	Max. Elevation	Std. Dev.
1	Hand	28	2050.74	2045.27	2026.23	2121.58	19.52
1	2014	28	2051.89	2047.59	2027.68	2121.07	18.35
		Adjustment	**+1.15**	**+2.32**	**+1.45**	**-0.51**	**-1.17**
2	1994-1997	42	2052.64	2046.85	2026.09	2114.39	18.66
2	2014	42	2052.95	2047.31	2027.68	2117.90	18.85
		Adjustment	**+0.31**	**+0.46**	**+1.59**	**+3.51**	**+0.19**
3	1999	64	2078.18	2061.03	2015.63	2164.29	37.07
3	2014	64	2078.34	2061.49	2015.63	2164.29	36.99
		Adjustment	**+0.16**	**+0.46**	**0.00**	**0.00**	**-0.08**
4	2000-2012	12	2150.30	2186.95	2054.96	2254.43	73.01
4	2014	12	2150.37	2186.77	2055.96	2254.43	72.80
		Adjustment	**+0.07**	**-0.18**	**+1.00**	**0.00**	**-0.21**

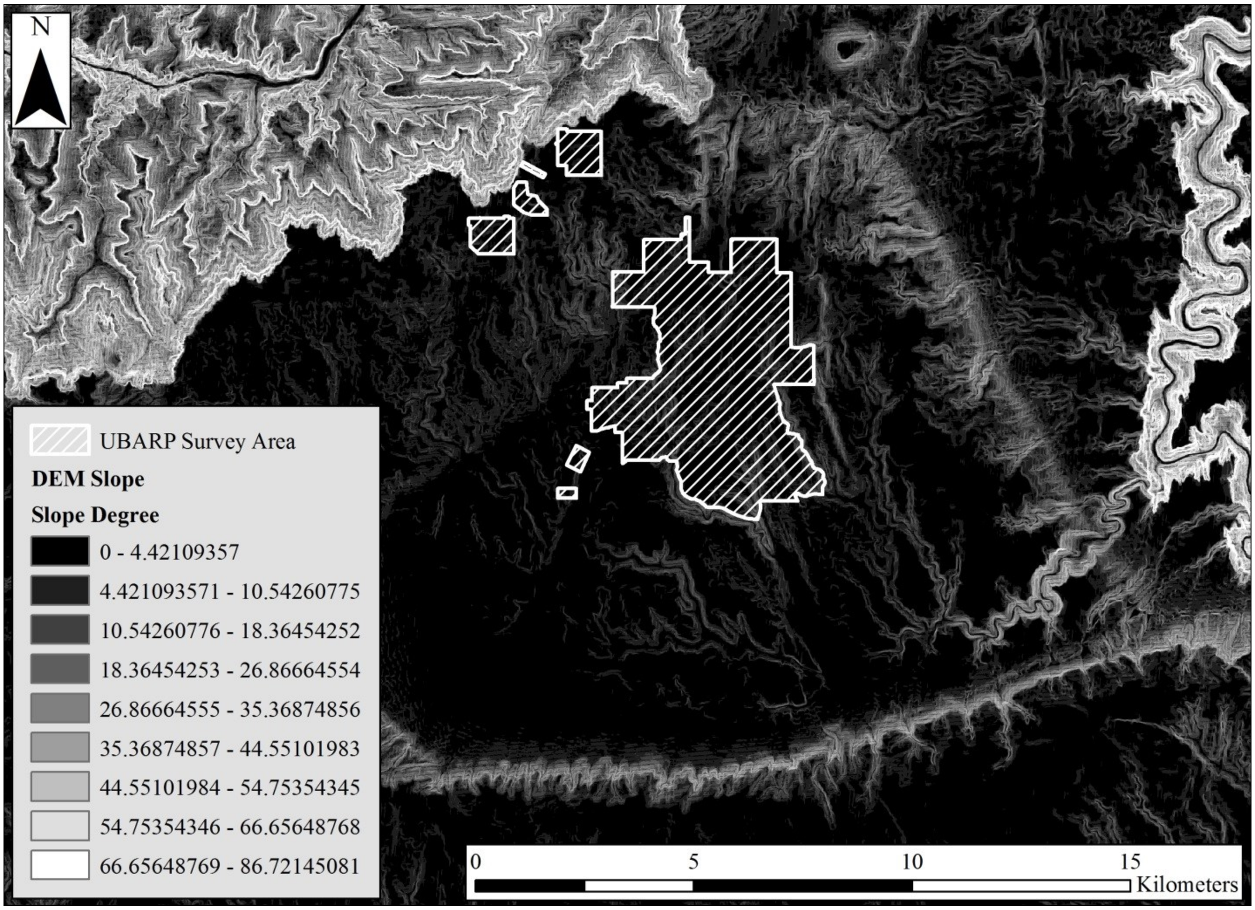


Figure 4.10. 10 meter slope degree image of the Upper Basin area.

Table 4.11. Average slope adjustment between previous MU locations and 2014 locations per GPS phase.

GPS Phase	GPS Year(s)	# MUs	Mean Slope	Median Slope	Min. Slope	Max. Slope	Std. Dev.
1	Hand	28	3.31	2.46	0.75	12.67	2.52
1	2014	28	2.85	2.40	0.97	79.71	1.49
		Adjustment	**-0.46**	**-0.06**	**+0.22**	**+67.04**	**-1.03**
2	1994-1997	42	3.26	2.48	0.76	9.31	2.09
2	2014	42	3.07	2.35	0.79	8.67	1.83
		Adjustment	**-0.19**	**-0.13**	**+0.03**	**-0.64**	**-0.26**
3	1999	64	3.35	2.58	0.46	12.62	2.26
3	2014	64	3.50	2.64	0.80	12.63	2.45
		Adjustment	**+0.15**	**+0.06**	**+0.34**	**+0.01**	**+0.19**
4	2000-2012	12	4.05	3.58	1.13	9.71	2.27
4	2014	12	3.96	3.58	1.13	9.57	2.24
		Adjustment	**-0.09**	**0.00**	**0.00**	**-0.14**	**-0.03**

Feature Type Variability Analysis

The final test for this study examines how the archaeological record of the Upper Basin, as documented by UBARP, has evolved compositionally. The rate of discovery of different feature types (masonry structures, lithic scatters, etc.) has not been uniform during the last 25 years. One possible reason for this pattern may be changes in GPS technology. This last analytical component of the overall study is designed to reveal the precise rate of discovery of different feature types per year.

For this test, I created a new attribute column in the 2015 MSD to register the year of first recording for each MU. These data were gathered from all survey transect forms, artifact enumeration forms, and field notebooks used during UBARP's field seasons. Using this information and SPSS, I was able to generate histograms to display the quantities of survey types discovered per year (see Appendix B). The results of this analysis are perhaps more dramatic than any other performed in this study. However, attributing the cause of these conspicuous year-to-year changes solely to differences in GPS technology may be a precarious argument. Other factors that may have influenced the rate of discovery of new feature types include, but are not limited to: survey crew size, field season length, the primary purpose for each field season, and a heterogeneous archaeological landscape (Sullivan et al. 2007:326; Thompson 2003). The first three of these factors are readily quantifiable and are included with this analysis (Figure 4.12 and Table 4.13).

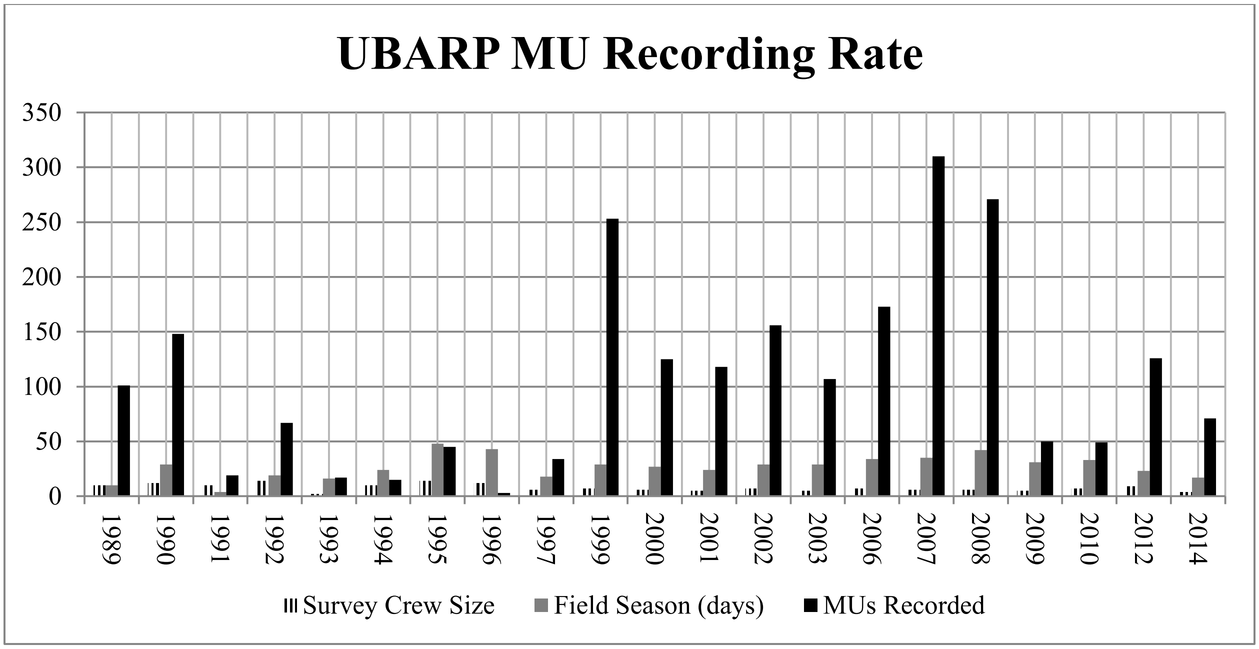


Figure 4.12. Yearly rate of MU recording, survey crew size, and field season duration (days).

Table 4.13. Yearly rate of MU recording, survey crew size, and field season duration (days).

Year	Survey Crew Size	Field Season Days	MUs Recorded
1989	10	10	101
1990	12	29	148
1991	10	4	19
1992	14	19	67
1993	2	16	17
1994	10	24	15
1995	14	48	45
1996	12	43	3
1997	6	18	34
1999	7	29	253
2000	6	27	125
2001	5	24	118
2002	7	29	156
2003	5	29	107
2006	7	34	173
2007	6	35	310
2008	6	42	271
2009	5	31	50
2010	7	33	49
2012	9	23	126
2014	4	17	71

Chapter 5 – Results

In the 25 years of UBARP's history, more than 2,200 Mapping Units (MUs) have been established with intensive surveys across 24 km^2 of the Upper Basin. The locations of these MUs were plotted using various cartographic and GPS techniques, ranging from hand-plotting with aerial photos in the earliest years to high accuracy differentially-corrected GPS in 2014. This diverse mapping toolkit, considered alongside UBARP's temporal longevity and spatial extent across the landscape, has provided an excellent case study for determining how, if at all, the conceptions of the archaeological record are modified by changes in geospatial technologies.

The results of four distinct analyses described in the previous chapter suggest that evolving geospatial methods and capabilities may have a tangible, if miniscule, effect on the spatial characteristics of the archaeological record. Furthermore, the results of the fourth analysis support the conclusion that the ability to spatially discern archaeological feature types during survey is strongly tied to the precision of any employed GPS technology. Each of these analyses is described in detail below.

Mean Locational Change

The first analysis examined the displacement of MU locations across the landscape in an absolute, Euclidean manner. This analysis looked exclusively at the degree to which 118 MUs were adjusted from earlier locations during ground-truthing field work conducted in 2014. As predicted, MU locations recorded in earlier GPS Phases, on average, were further from their actual ground locations than MUs recorded more recently. Figure 5.1 shows the dramatic adjustments made when hand-plotted coordinates from GPS Phase 1 were compared against their 2014 coordinates. As noted previously, however, all MUs ground-truthed in 2014 were relocated using their most recent GPS coordinates, and so the examination of Phase 1 locations—which are not GPS-based—represents a hypothetical mean adjustment. The smoothly decreasing mean adjustment trend of this analysis can be seen in Figures 5.1 and 5.2. Interestingly, during field work in 2014 the survey crew revisited one MU last recorded in 1994, which did not require spatial adjustment.

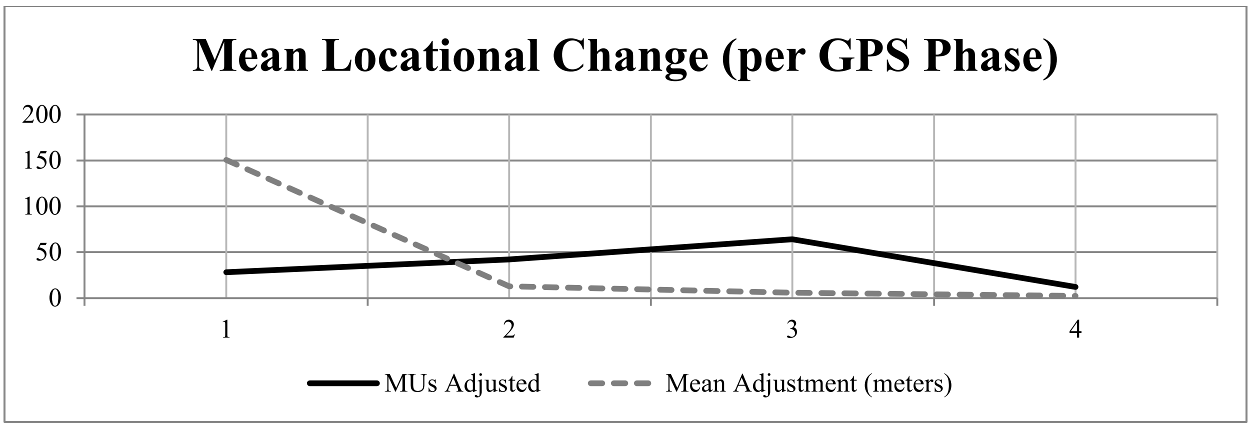


Figure 5.1. Average adjustment of MUs from previous locations to 2014 locations, per GPS phase.

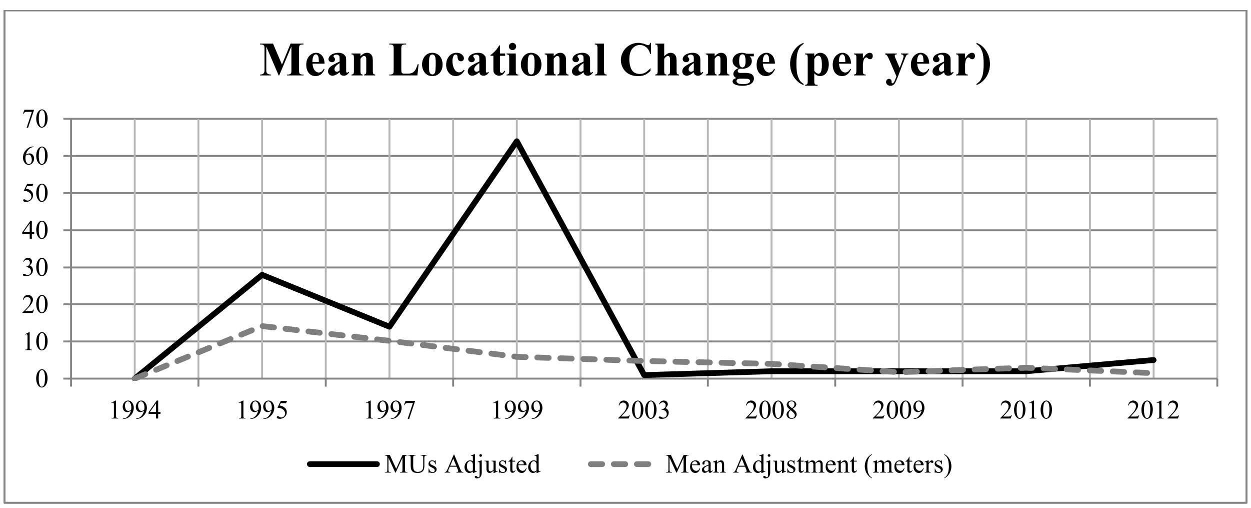


Figure 5.2. Average adjustment of MUs from previous locations to 2014 locations, per year.

Whether analyzed in grouped GPS Phases or by individual years, the trend towards increased spatial accuracy over time is fairly conspicuous. This pattern falls in line with the expected performance characteristics of each GPS suite (rover, antenna, base station, etc.) used during UBARP (Howard 2007; Wheatley and Gillings 2002:73). Based on this analysis, it should be safe to conclude that archaeological work concerning broad spatial relationships inferred from early years of civilian GPS, and especially from time periods prior to GPS, may require reconsideration (Howard 2007).

As part of this analysis, I also examined how archaeological feature types may have influenced spatial accuracy, and proportionally, mean locational adjustment. It was an initial assumption of this study that two feature types in particular, lithic scatters and sherd & lithic scatters, would have the highest mean adjustment based on their diffuse nature and subjective centroid locations. The results shown in Figure 5.3 support this hypothesis. FCR piles, which were not expected to adjust tremendously, also had a relatively high mean adjustment. One extremely adjusted wood hogan (MU 313.12, at 69.5 meters) set that feature type's mean adjustment apart from all other feature types. MU 313.12 appears to be statistically abnormal, given that the next highest adjustment for any MU is 35 meters. No other pattern of increasing or decreasing spatial accuracy is readily discernible based on feature type.

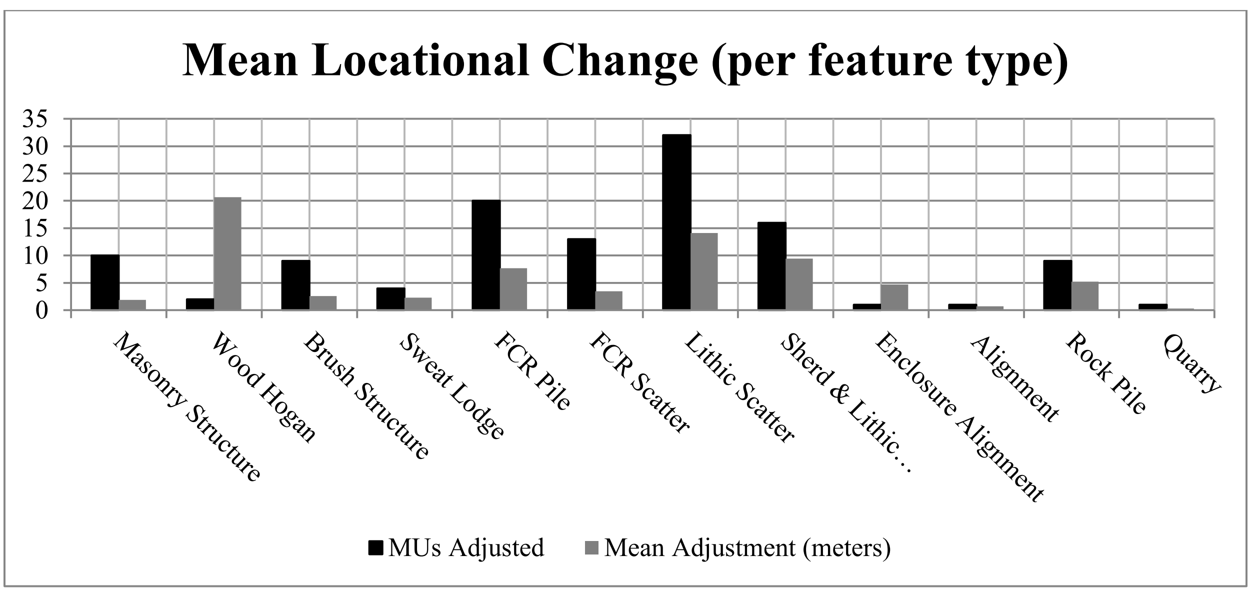


Figure 5.3. Average adjustment of MUs from previous locations to 2014 locations, per feature type.

Nearest Neighbor Analysis

The second analysis determined the relative changes in position for all 118 adjusted MUs by examining whether locations (2014 or previous) exhibited clustering or regular dispersion. The results of this analysis speak, not to the spatial accuracy, but to the spatial distribution of archaeological phenomena, and to those levels of regional inferences that rely on precisely how patterns across a landscape are interpreted (Bevan and Conolly 2006:218). As with the first analysis, the average nearest neighbor test was conducted to observe changes across GPS Phases, years, and feature types.

The first of these tests (Figure 5.4) based on GPS phases resulted in a pattern similar to that shown in Figure 5.1, with a noticeable adjustment visible in Phase 1 (hand-plotted) locations. However, contrary to the mean locational change test, the nearest neighbor analysis showed a very slight increasing trend in NN observed adjustments across time (Figure 5.5). NN observed is not a direct correlate to spatial accuracy, and so these results do not necessarily contradict the results of the mean locational change analysis. NN observed is a measure of the average distance between points, and so changes in this factor denote only changes in spatial distribution (Wheatley and Gillings 2002:129). It is worth noting that the Average Nearest Neighbor tool in ArcMap performs better with a larger sample size, and fewer points often produce low integrity results (ESRI 2013a). The NN observed values for years 2003-2012 appear more extreme as there are fewer samples in those years. This resultant pattern is not unlike the effect that MU 313.12 had in the first analysis, whereby a low number of samples without a consistent trend possessed an extreme mean.

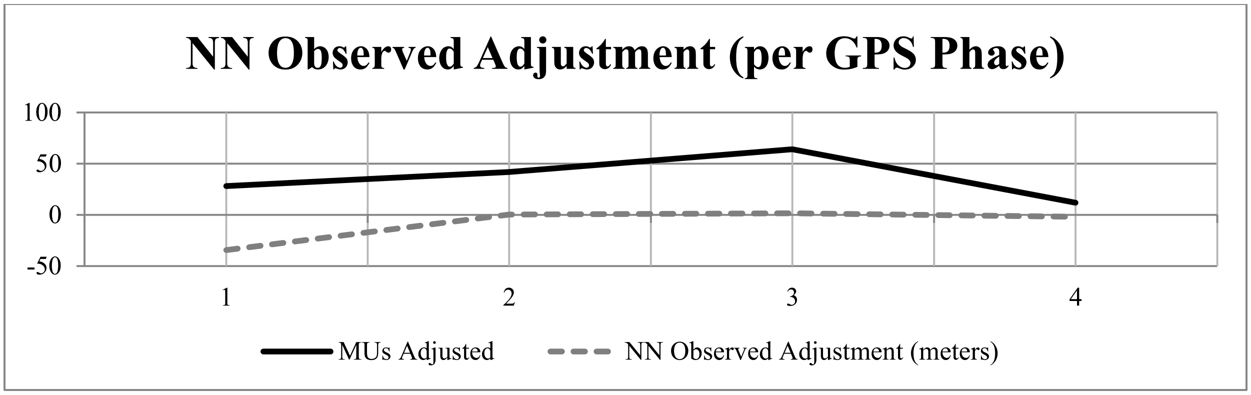


Figure 5.4. Adjustment between NN Observed values at previous locations and at 2014 locations, per GPS phase.

The results of the nearest neighbor analysis, when considered per year, do not present any obvious relationship between year and NN observed adjustment (Figure 5.5). As mentioned above, the increasingly dynamic adjustments for years 2003-2012 are likely attributable to the very low sample numbers of those years. For this reason, using nearest neighbor analysis to determine the effects of specific GPS devices on spatial patterns, at least in this study, does not appear to be a profitable venture.

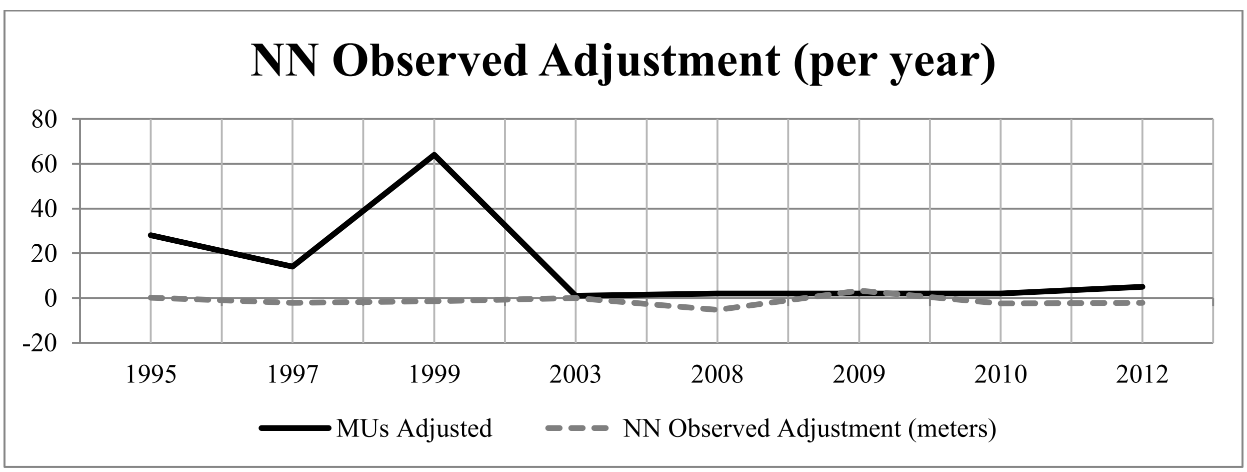


Figure 5.5. Adjustment between NN Observed values at previous locations and at 2014 locations, per year.

Lastly, performing a nearest neighbor analysis on survey types did not generate any readily apparent correlation between NN observed and specific types of archaeological features. Only the wood hogan type demonstrated an unambiguous adjustment, although again, this is due to the extreme deviation between MU 313.12's original and 2014 locations, and is not attributable to the archaeological nature of the feature type. Also, unlike the mean location change analysis, which predicted two scatter types being especially likely to adjust (lithic scatters and sherd & lithic scatters), no feature types were expected to adjust towards clustering or regular dispersion from the outset of this study, as Figure 5.6 illustrates. The results of this nearest neighbor analysis fail to suggest that the characteristics of any feature type have a particular influence over that type's spatial distribution.

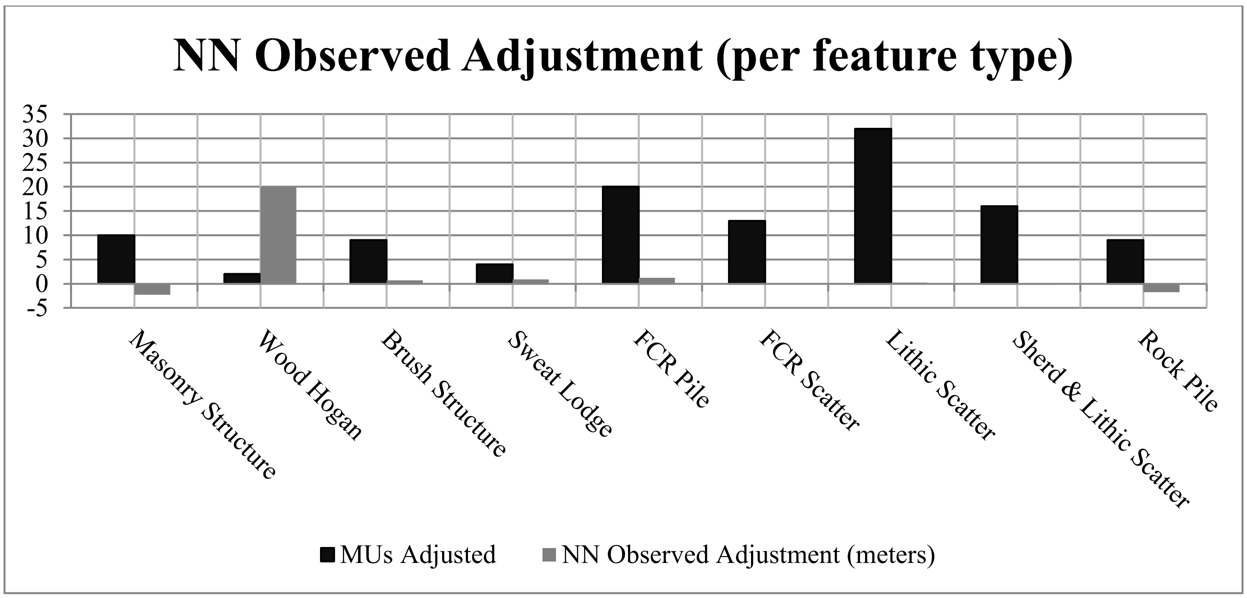


Figure 5.6. Adjustment between NN Observed values at previous locations and at 2014 locations, per feature type.

Locational Attribute Query

The third analysis in this study observed the movement of MU locations across other spatial layers as they were adjusted to 2014 coordinates. The layers used in this analysis included jurisdictional boundaries (Kaibab National Forest and Grand Canyon National Park), soil phases (as defined by NRCS and the USDA Forest Service), elevation, and slope. The latter three of these attributes are commonly employed during surveys to define the environmental characteristics of archaeological phenomena (Banning 2002). For this reason, it is imperative that each MU is located as accurately as possible with respect to environmental boundaries.

Each of these tests was conducted with ArcMap using the Search by Location tool. Figure 5.7 displays the results when MUs were queried for movement across each spatial layer based on GPS phase. No MUs were adjusted across jurisdictional boundaries in this test, and therefore, the jurisdictional query was excluded from the “per year” and “per feature type” tests (shown below). As well, a total of four MUs adjusted across soil types; two in Phase 1, and one each in Phases 2 and 3. With such a low number of adjustments, running the soil type query per year and per feature type would not have revealed any statistically significant patterns, and so the soil type was omitted from further testing.

As shown in Figure 5.7, the results of the GPS phase-based test are consistent with those of the counterpart mean locational change test (see Figure 5.1). MUs at their hand-plotted coordinates in Phase 1 adjusted the greatest amount across soil type, elevation, and slope. The trend towards zero adjustment is readily apparent and fits the expectations of this study for increased spatial accuracy over time.

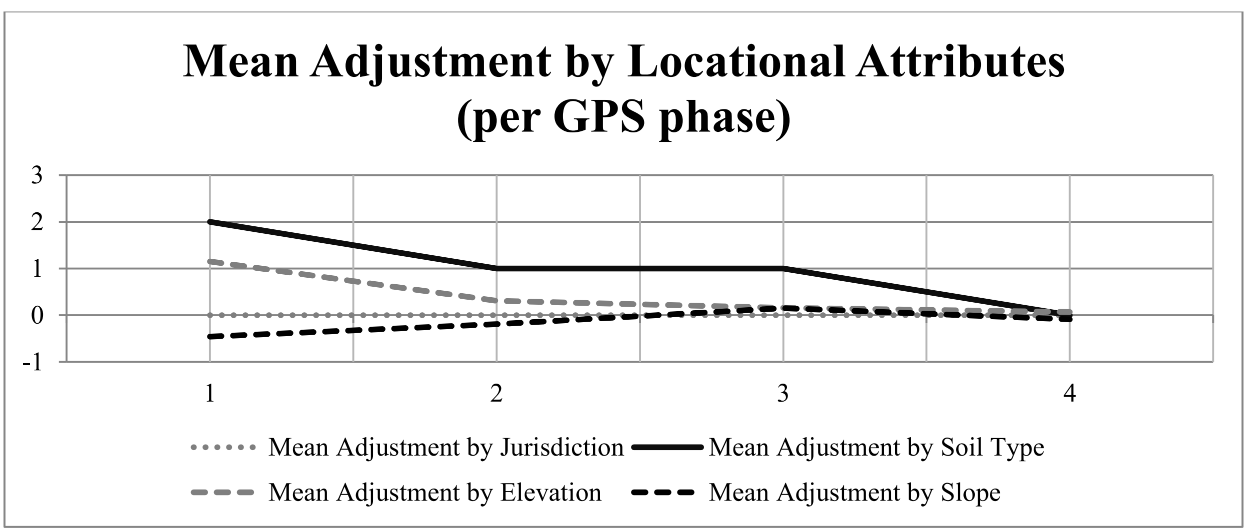


Figure 5.7. Average adjustment of MUs across locations, elevation, and slope, per GPS phase.

Two environmental attributes, elevation and slope, were further tested for changes per year and per feature type. Elevation and slope are not mutually inclusive variables, as one can change across the landscape without necessarily requiring a proportional change in the other. Figure 5.8 shows the results of the yearly-based test, which indicate a slight, though highly dynamic, trend towards decreased adjustment over time. The lines depicted in this figure represent the adjustment between mean elevation (meters above sea level) at the original coordinates for MUs last recorded in 1995, 1997, etc., and the mean elevation for those same MUs at their 2014 coordinates. Mean slope adjustment works the same as mean elevation, although it is measured in degrees. It is worth reiterating again that only 12 samples of adjusted MUs were used in the generation of these lines after 1999, and so some trepidation is suggested when evaluating adjustments made during GPS Phase 4.

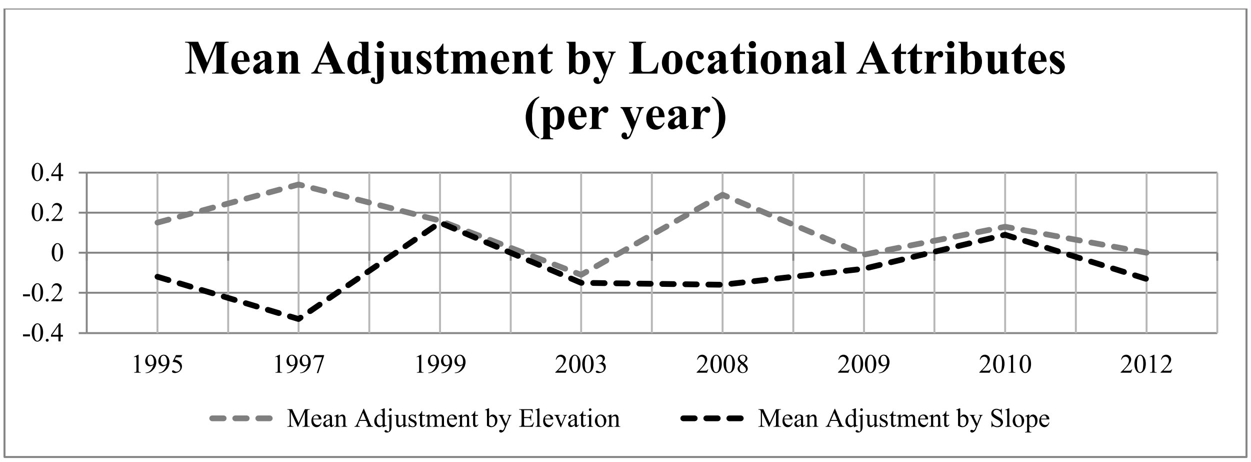


Figure 5.8. Average adjustment of MUs across locations, elevation, and slope, per year.

The final test in this locational attribute analysis compared the adjustments of survey types across elevation and slope. For the purposes of illustration, I stacked the mean adjustment results for both elevation and slope to more accurately reflect the propensity for certain feature types to adjust (Figure 5.9). As with the previous analyses, the wood hogan type dominates the adjustment scale, which is expected due to MU 313.12's extreme adjustment across the landscape. These adjustments are somewhat similar to the results of the mean locational analysis (see Figure 5.1), although the lithic scatter and sherd & lithic scatter types would have been expected to adjust more prominently. However, these scatter types are often found on fairly flat surfaces, which may explain their minimal slope adjustment values. Interestingly, masonry structures and brush structures appear to have adjusted considerably in slope aspect from their previous locations, in spite of not having moved much laterally. For the purposes of this study, I place more significance in the mean locational change analysis than the locational attribute query. Still, the results of this analysis shed light on the importance of ensuring locational accuracy when it comes to defining the environmental characteristics of the archaeological record.

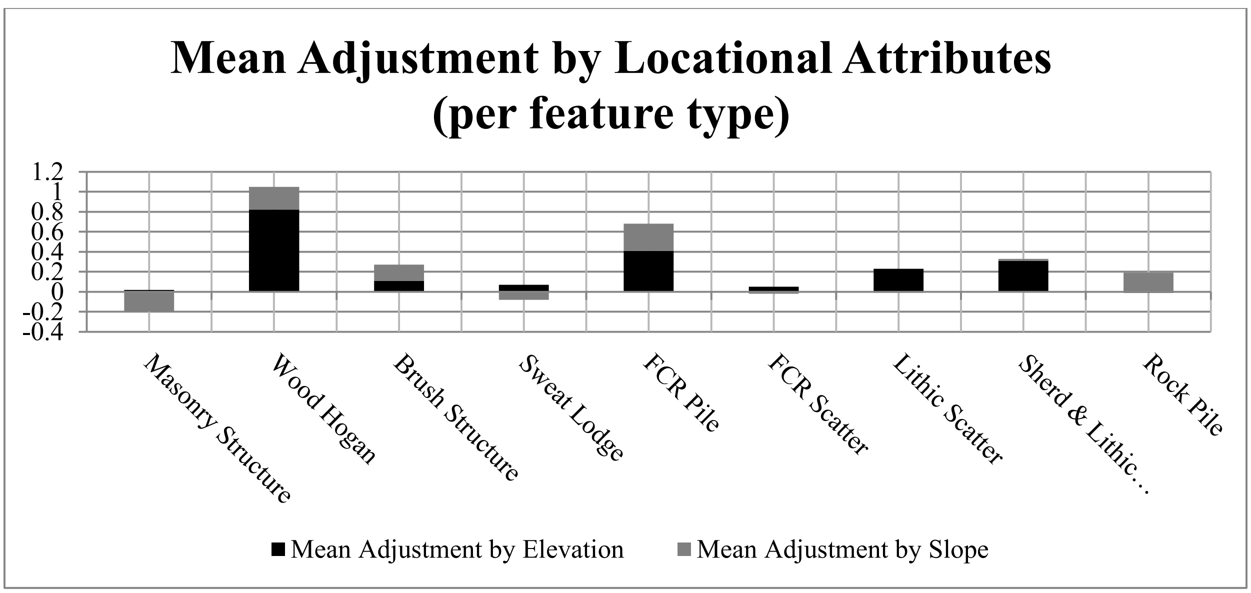


Figure 5.9. Average adjustment of MUs across locations, elevation, and slope, per feature type.

Survey Type Variability

Lastly, the final analytical component of this study examined the MU discovery rate of UBARP during the past 25 years. This rate has not been consistent, and for that reason, three other variables were considered alongside the number of MUs discovered each year. It was an initial assumption of this study that survey crew size and field season length would have had a direct influence on the MU discovery rate. As well, the purpose of each field season (whether primarily for excavation or survey) and the heterogeneous archaeological/natural environment under study should have a strong influence over this rate. The latter of these variables, the heterogeneous landscape, has been excluded from analysis due to the difficulty in quantifying such a factor.

Figure 5.10 displays the recording rate for MUs from each year that field work was conducted by UBARP. Survey crew size and field season duration are included for comparison. Based on this chart, there may be a slight correlation between the MU discovery rate and field season duration, while survey crew size does not appear to have played a major role. Perhaps what is more important is the purpose of each field season. The conspicuous lull in the MU discovery rate between 1991 and 1997 may be entirely attributable to the primacy of excavations over surveying taking place during that period. To further this hypothesis, survey crew size numbered 10-14 persons for all but one of the years between 1991 and 1997, while every year since then has seen 9 or fewer members. This pattern all but refutes any correlation between survey crew size and the MU discovery rate.

Table 5.10. Primary purpose of each field season (Thompson 2003).

Year	Excavation	Survey	Ground-Truthing
1989		●	
1990	●	●	
1991	●		
1992	●		
1993	●		
1994	●		
1995	●		
1996	●		
1997			●
1999		●	
2000	●	●	
2001		●	
2002	●	●	
2003		●	
2006		●	
2007		●	
2008			●
2009			●
2010		●	
2012		●	
2014			●

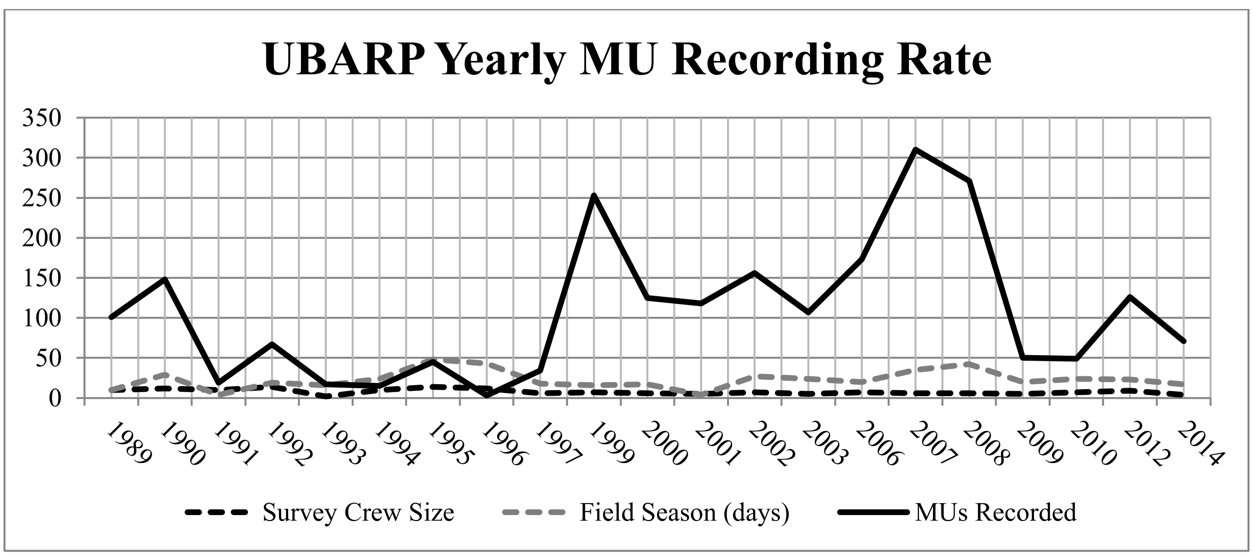


Figure 5.11. UBARP yearly recording rate of MUs, with survey crew size and field season duration for comparison.

Based on this observation, the overall rate of MUs discovered per year is not directly influenced by the number of surveying crew members, and is only marginally affected by field season duration. The primary purpose behind each field season appears to be a strong determinant for this rate. Of further consideration, however, is the effect that changing GPS technology may have had on how quickly, and how discretely archaeological features could be recorded. MUs discovered during GPS Phase 1 were recorded via a lengthy process of using aerial photos and subsequent USGS topographic maps to determine locations. This procedure severely limited the rate at which MUs could be discovered each day during UBARP's early years. Furthermore, these early MUs were markedly broad in their coverage of archaeological features, due to the inability to discern closely associated phenomena on an aerial photograph (Schiffer et al. 1978). Therefore, many MUs established during GPS Phase 1 were later disaggregated into multiple different features when GPS became available in later phases.

The ability to distinguish archaeological features on the landscape has been intrinsically tied to two factors: the performance capabilities of each GPS suite employed, and the discernibility of each feature type. As mentioned above, prior to 1994, UBARP conducted its survey work without the aid of GPS, which invariably constrained the rate of MU establishment. When the first GPS device was utilized by UBARP in 1994, survey crews gained an expedited means of recording new MUs. However, the first period of GPS use, GPS Phase 2, was hampered by the necessity, and crude reliability, of field base stations used for differential correction (see Chapter 3). The MU discovery rate, although increased from the previous GPS Phase, was still encumbered by an inefficient recording system. In 1999, the UBARP crew was able to make use of community, rather than field, base stations for the first time (Snay and Soler 2008:96). Without the burden of setting up and tearing down a field base station each day, survey crews were able to maximize their time in the field and reach one of the highest rates of annual MU discovery in UBARP's history. The only functional difference between GPS Phases 3

(1999) and 4 (2000-2014) is whether Selective Availability (SA) was active or not. Given that SA appears to have played no major role in the spatial accuracy of differentially-corrected GPS locations, I can conclude that the watershed moment for UBARP's survey efficiency took place in 1999 with the switch to community base stations.

The second major factor influencing the rate at which archaeological phenomena have been recorded by UBARP is the discernibility of the survey types themselves. Table B.1 charts the recording rate for the nine most prevalent survey types in the 2015 Master Survey Database (MSD). Prior to 1999, only four feature types were consistently represented by survey work: masonry structures, fire-cracked-rock piles, lithic scatters, and sherd & lithic scatters. These feature types are common and ubiquitous throughout UBARP's study area, while the others (and those feature types not included in Table B.1) are considerably rarer. As well, evolving expectations and definitions of what constitutes the Upper Basin's archaeological record have provided new feature types, such as fire-cracked-rock scatters and functionally distinct alignments that did not yet "exist" in UBARP's earliest surveys. Thus, an adaptable understanding of archaeological phenomena, coupled with the rapid and discrete recording rate of GPS, particularly after community base stations became available, enabled UBARP to greatly accelerate the rate and diversity of MU discoveries after 1997.

Chapter 6 – Conclusion

Based on the general consensus of the four analyses discussed in Chapter 5, I conclude that the evolution of mapping and recording technology has had a quantifiable effect on the characteristics of the archaeological record investigated by UBARP. This conclusion is supported by the results from the mean-locational-change analysis and locational-attribute query, which demonstrate a fairly clear signature of increased spatial accuracy over time commensurate with increased GPS performance capabilities. Without question, Mapping Unit (MU) locations recorded manually during GPS Phase 1 (1989-1993) were the least spatially accurate and most likely to be recorded with incorrect attribute information. Comparatively, GPS Phase 4 MU locations (2000-2014) adjusted the least in nearly every measure. The spatial and attributional accuracy spectrum between Phases 1 and 4 exhibits a fairly smooth trend of increasing locational precision. With this information, it is arguably clear that archaeological research based on survey work conducted prior to GPS, and during civilian GPS's infancy, is worthy of scrutiny.

Though not indicative of GPS's role in spatial *accuracy*, the nearest neighbor analysis revealed that adjusting the locations of MUs can have a small but noticeable effect on their spatial *distribution*. Any research project aimed at determining settlement patterns is wholly dependent upon the integrity of the spatial data used to makes such inferences (Bayman and Sanchez 1998; Bevan and Conolly 2006:219). Therefore, it is essential to landscape archaeology that archaeological phenomena are registered as faithfully as possible to their actual ground locations (for challenges in surveying, see Ammerman 1981; Wandsnider 1998). This nearest neighbor analysis served to demonstrate the hazards involved in relying on faulty locational information to determine regional spatial patterns (Conolly and Lake 2006:29). The results of this analysis, however, do not directly imply that differing GPS technology had influenced these spatial patterns in any consistent manner (i.e., increased or decreased clustering through time).

Analysis of feature type variability, the final consideration in this study, provided a dramatic illustration of how the rate of archaeological discoveries can be influenced by changes in GPS technology. Specifically, the process of recording an MU's location accelerated after GPS was introduced to survey crews, and then accelerated further after the switch from field to community base stations. GPS effectively increased the propensity to disaggregate MUs, which improved the efficiency of archaeological feature recognition and, as explained above, increased the spatial accuracy of these phenomena for analytical purposes.

Each of the factors discussed in the previous paragraphs serves to support the underlying hypothesis of this study: certain spatial and attributional characteristics of the archaeological record are invariably influenced by the use of GPS technology. If inferences are to be drawn from surveys conducted prior to, and during the earliest periods of GPS, considerations must be made for how these distortions may influence the results of regional level archaeological projects (Howard 2007). As this study concerning the evolution of UBARP's archaeological record has shown, the tools used to record *where* archaeological phenomena are located can have a significant impact on *what* is being discovered (Salisbury 2009:7).

Significance of Scale and Unit of Observation

Of particular importance to the implications of this study are two concepts that often define archaeological interpretations, sometimes without serious consideration: scale and the unit(s) of observation. Burger and Todd (2006:251) argue that, "For most archaeological concerns, understanding the relationship between the sample [scale] and the target population is a fundamental first step to building accurate interpretations." Both scale and unit of observation have a tremendous influence over the perspective of regional scale archaeology, and yet, these concepts are often taken for granted (Gumerman 1988:2; Harris 2006:42; Wobst 2006:58). As this study deals exclusively with landscape-level inferences and conclusions, rather than on a site-by-site basis, it is necessary to explore in some detail how the scale of analysis may have influenced the results.

The term "scale" is often ambiguously used to define a study area's range or extent, and the depth of coverage used to analyze that area (Lock and Molyneaux 2006). It is critical to understand that modifying either of these factors (extent and/or depth of coverage) can change the interpretive potential of the study and produce a variety of answers to a single research question (Harris 2006:47; Ridges 2006:146; Salisbury 2009:4). Of the four analyses in this study, the most heavily influenced by changes in scale is the nearest neighbor analysis. The results of this analysis are based exclusively on the study area's extent and how points within that extent are arranged (Bevan and Conolly 2006:219). For example, twenty MUs may appear randomly dispersed across the landscape when viewed at a 100 m^2 extent, but form one cluster when viewed at 1 km^2. Depending on which scale was used in this example, the archaeological record may register two very different interpretations (Figure 6.1) (Church et al. 2000). It is essential to operate with a consistent scale for each analysis, a strategy which was used throughout the course of this study (Burger and Todd 2006:252).

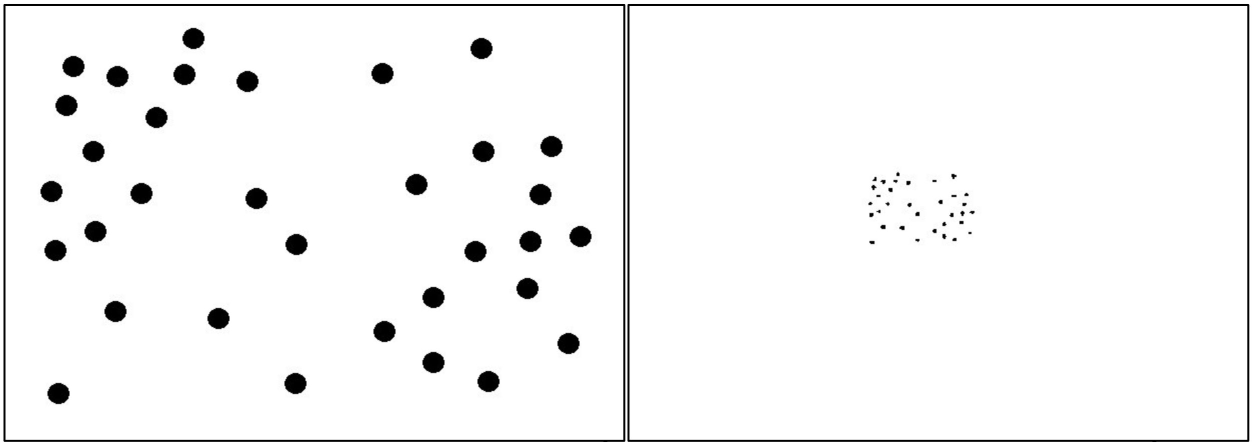


Figure 6.1. Example MU distribution at 100 m^2 scale (left, randomly dispersed) and 1 km^2 (right, tightly clustered).

The unit of observation, or grain of analysis, sets the reference point for spatial analyses (Burger and Todd 2006). If this study were concerned with only a single site, the unit of analysis may be specific features of the site, such as middens, rooms, or hearths. The use of individual artifacts as the unit of observation has also been suggested for studies at this scale (Burger and Todd 2006:239). This study uses individual MUs as the default unit of observation because the focus is at the regional level (Sullivan et al. 2007). MUs, by their conceptualization, are less susceptible to behavioral expectations and meanings, which results in the recording of higher numbers of anthropogenic features on the landscape than the 'site' concept allows for (Sullivan 2007).

MUs are represented cartographically as points on the landscape, which has been the standard convention in archaeology (Conolly and Lake 2006; Haigh and Kelly 1987; Mink et al. 2006). Performing spatial analyses on points is fairly straightforward and provides the most discrete indications of movement across a landscape. In this study, the mean locational change analysis, nearest neighbor analysis, and locational attribute query were facilitated by defining MUs as single points.

However, of further consideration is the use of polygons, rather than points, to cartographically and analytically represent variation among MUs. For example, 2,236 MUs have either measured or estimated areas that can be used to generate areal buffer zones in ArcMap around their point locations (Figure 6.2). This process creates a more appropriate representation of an MU's "footprint on the landscape" than can be inferred or visualized with a single point, although true representation may be hampered by the "fuzziness" of indiscrete feature types (Conolly and Lake 2006:29; Mink et al. 2006; Newhard et al. 2013). By extension, the density of archaeological materials on the surface may be more comprehensively visualized with polygons, as well. Furthermore, when assessing potential project impacts to sites, polygons can more accurately represent at-risk sites than points (Mink et al. 2006). The applicability of this alternative method for visualizing and analyzing traces of the archaeological past cannot be overstated, and should be investigated further.

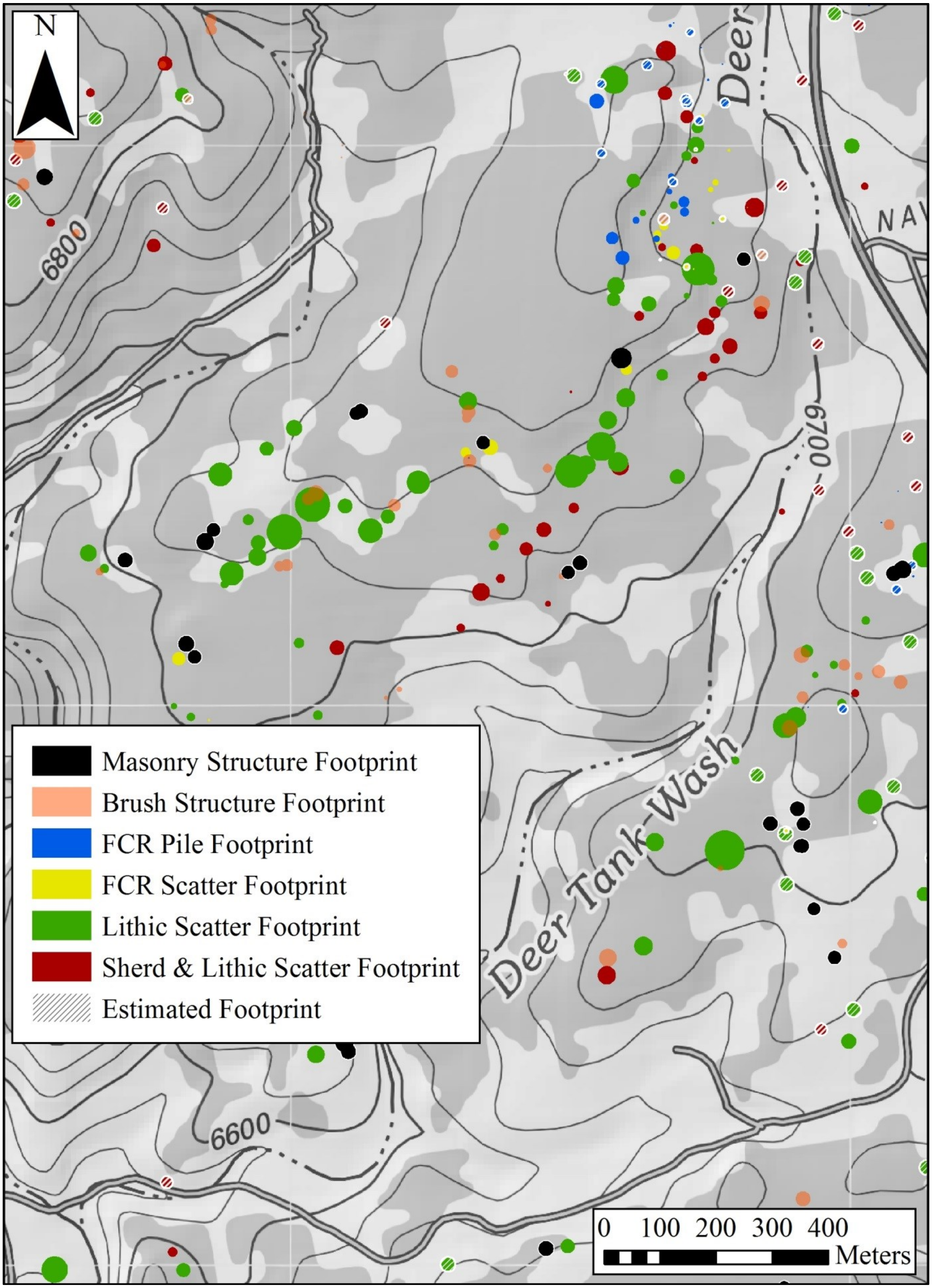


Figure 6.2. Example of variation among MUs as polygonal "footprints."

Discussion

As a field that studies the locations of things in space, archaeology is especially well-positioned for the tools and techniques of GIS (Conolly and Lake 2006:10; Daly 2009:21; Wheatley and Gillings 2002). It could be argued that conducting archaeology necessitates, at the very least, a prospective glance into the fundamental concepts of geography and information science (Llobera 2011). The advent of GIS and its applications for archaeological research have led these two fields to become intimately aware of each other, and the growing relationship is unlikely to sever, given the power of GIS in answering archaeological questions (Daly 2009; Stine 2000:61; Washam 2014:82). For these reasons, this study made use of a GIS to disentangle the exchange between GPS capabilities and the survey-based archaeological record of the Upper Basin. The results, discussed above, represent perhaps an initial step towards a better understanding of this complex relationship.

Without a doubt, GPS devices have dramatically accelerated the rate at which archaeological surveys can be conducted (Conolly and Lake 2006:61; McCoy and Ladefoged 2009; Wheatley and Gillings 2002:72). As Fitts (2005:18) correctly predicted, "With the standardization of technology and output, GPS is getting cheaper, more accessible, and more pervasive, and as a result of their increasing capabilities, GPS receivers will become the standard approach for archaeological surveying in the near future." Furthermore, the accuracy of data collected during those surveys has increased, not only spatially, but also in regards to the attributes associated with those sites' locations (Conolly and Lake 2006:63). As this study shows, increased GPS performance characteristics lead directly to increased accuracy of site locations, improved environmental attribute data, and an increased rate of site discovery. Most importantly, evolving GPS technology has increased the potential diversity of site types via improved designation and recording techniques, as well as modifying the patterns of site distribution across the landscape. Clearly, GPS plays a significant role in our understanding of archaeological phenomena at the regional or macro scale (Howard 2007).

It is important to make the distinction that employing different GPS technologies does not change the actual locations of sites, but rather our spatial interpretations of them. Attempting to represent archaeological phenomena in a two-dimensional medium, no matter how accurate the locational data, is an imperfect process imperiled by numerous physical limitations and distortional errors (Costopoulos et al. 2010:6). By recording site locations with the most accurate GPS technology, it is possible to reduce that margin of error somewhat. Today's GPS devices possess the capability for sub-meter accuracy when differentially corrected, which is more than sufficient for the purposes of landscape archaeology (Conolly and Lake 2006:63). However, at the landscape scale, few archaeological features are best represented with point locations, no matter how accurate. Nor are all features discrete enough on the ground to be represented by hard polygons; lithic scatters, for example, rarely have well-defined boundaries or central densities (Conolly and Lake 2006:29). Thus, the cartographic depiction of archaeological phenomena is often plagued by either an oversimplification or an exaggeration of site extent, discreteness, and material density (Conolly and Lake 2006:35). Developing a solution to this representational obstacle is a challenge worthy of further effort.

For the present, revisiting archaeological sites whose locations were last recorded manually, with modern GPS devices, should be considered a top priority (Hey 2006:125). If the general inaccuracy of GPS Phase 1 locations found in this study is indicative of errors among manually plotted sites, the discipline may require some major housekeeping of its spatial data. Kvamme (1999:183) mirrored this sentiment, stating, "If archaeological data are sloppy, then we need to change our recording habits and employ appropriate technology such as global positioning systems (GPS)." Increasing the spatial integrity of our data may lead to an improvement in not only the manner in which sites are visualized, but also the inferential potential of those sites (Gibbs 2012; Wheatley and Gillings 2002:18). The results of this study lend support for the urgency and necessity of this endeavor.

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Appendix A – Additional Analysis Results

Table A.1. Average locational adjustment between previous MU locations and 2014 locations per year.

Year	Adjusted	GPS Device	Mean Change	Median	Max	Std. Dev.
1994	0	Navigation Pathfinder Basic+	--	--	--	--
1995	28	Navigation Pathfinder Basic+	14.19	11.67	35.08	9.48
1997	14	Navigation Pathfinder Basic+	10.21	10.81	22.16	7.28
1999	64	GeoExplorer II	5.89	2.71	69.5	10.1
2003	1	GeoExplorer II	4.75	--	--	--
2008	2	GeoXH 2005	3.97	3.97	6.74	3.92
2009	2	GeoXH 2005	1.74	1.74	3.38	2.32
2010	2	GeoXH 2005	2.94	2.94	3.91	1.37
2012	5	GeoXH 2005	1.45	1.36	2.87	0.87

Table A.2. Average locational adjustment between previous MU locations and 2014 locations per feature type.

Feature Type	# MUs	Original GPS Years	Mean Change	Median	Max	Std. Dev.
Masonry Structure	10	1997-2012	1.87	1.28	6.74	2.02
Wood Hogan	2	1995-1999	20.65	20.65	35.08	20.41
Brush Structure	9	1999	2.58	2.34	5.09	2.00
Sweat Lodge	4	1999	2.30	1.97	3.63	0.90
Fire-cracked-rock Pile	20	1997-1999	7.70	1.97	69.50	15.63
Fire-cracked-rock Scatter	13	1995-2010	3.49	2.12	11.61	3.83
Lithic Scatter	32	1995-1999	14.09	11.32	34.13	9.05
Sherd & Lithic Scatter	16	1995-1999	9.44	9.98	22.47	5.70
Enclosure Alignment	1	1999	4.67	--	--	--
Alignment	1	1999	0.70	--	--	--
Rock Pile	9	1995-1999	5.21	2.80	17.76	5.89
Quarry	1	1999	0.31	--	--	--

Table A.3. Average nearest neighbor analysis adjustment between previous MU locations and 2014 locations per year.

Original Year(s)	GPS Year(s)	# MUs	NN Ratio	NN Z-Score	NN Expected	NN Observed	Clustering
1995-2012	Original	118	0.465	-11.126	289.99 m	134.73 m	99% Yes
1995-2012	2014	118	0.462	-11.171	289.69 m	133.97 m	99% Yes
		Adjustment	**-0.003**	**-0.045**	**-0.30 m**	**-0.76 m**	
1995	1995	28	0.752	-2.510	206.10 m	155.01 m	95% Yes
1995	2014	28	0.750	-2.532	206.89 m	155.14 m	95% Yes
		Adjustment	**-0.002**	**-0.022**	**+0.79 m**	**+0.13 m**	
1997	1997	14	1.051	0.363	383.71 m	403.16 m	Random
1997	2014	14	1.045	0.323	383.65 m	400.97 m	Random
		Adjustment	**-0.006**	**-0.040**	**-0.06 m**	**-2.19 m**	
1999	1999	64	0.499	-7.674	230.93 m	115.15 m	99% Yes
1999	2014	64	0.492	-7.780	231.15 m	113.65 m	99% Yes
		Adjustment	**-0.007**	**-0.106**	**+0.22 m**	**-1.5 m**	
2003	2003	1	--	--	--	--	--
2003	2014	1	--	--	--	--	--
		Adjustment	**--**	**--**	**--**	**--**	
2008	2008	2	171.710	461.855	42.93 m	7371.01 m	99% No
2008	2014	2	171.649	461.690	42.91 m	7365.76 m	99% No
		Adjustment	**-0.061**	**-0.165**	**-0.02 m**	**-5.25 m**	
2009	2009	2	155.251	417.324	38.81 m	6025.74 m	99% No
2009	2014	2	155.293	417.439	38.82 m	6029.06 m	99% No
		Adjustment	**+0.042**	**+0.115**	**+0.01 m**	**+3.32 m**	
2010	2010	2	5.398	11.898	1.35 m	7.28 m	99% No
2010	2014	2	4.397	9.192	1.10 m	4.83 m	99% No
		Adjustment	**-0.001**	**-2.706**	**-0.25 m**	**-2.45 m**	
2012	2012	5	2.307	5.593	195.79 m	451.76 m	99% No
2012	2014	5	2.300	5.560	195.55 m	449.67 m	99% No
		Adjustment	**-0.007**	**-0.033**	**-0.24 m**	**-2.09 m**	

Table A.4. Average nearest neighbor analysis adjustment between previous MU locations and 2014 locations per feature type.

Feature Type	GPS Year(s)	# MUs	NN Ratio	NN Z-Score	NN Expected	NN Observed	Clustering
Masonry Structure	1997-2012	10	1.129	0.781	648.65 m	732.42 m	Random
Masonry Structure	2014	10	1.126	0.760	648.62 m	730.12 m	Random
		Adjustment	**-0.003**	**-0.021**	**-0.03 m**	**-2.30 m**	
Wood Hogan	1995-1999	2	103.459	277.201	25.87 m	2676.04 m	99% No
Wood Hogan	2014	2	103.846	278.250	25.96 m	2696.02 m	99% No
		Adjustment	**+0.387**	**+1.049**	**+0.09 m**	**+19.98 m**	
Brush Structure	1999	9	0.981	-0.107	394.64 m	387.26 m	Random
Brush Structure	2014	9	0.982	-0.103	395.08 m	387.98 m	Random
		Adjustment	**+0.001**	**+0.004**	**+0.44 m**	**+0.72 m**	
Sweat Lodge	1999	4	3.743	10.494	135.70 m	507.89 m	99% No
Sweat Lodge	2014	4	3.742	10.492	135.96 m	508.78 m	99% No
		Adjustment	**-0.001**	**-0.002**	**+0.26 m**	**+0.89 m**	
Fire-Cracked-Rock Pile	1997-1999	20	0.768	-1.983	279.50 m	214.72 m	95% Yes
Fire-Cracked-Rock Pile	2014	20	0.773	-1.941	279.30 m	215.92 m	90% Yes
		Adjustment	**+0.005**	**+0.042**	**-0.20 m**	**+1.20 m**	
Fire-Cracked-Rock Scatter	1995-2010	13	0.862	-0.949	393.63 m	339.45 m	Random
Fire-Cracked-Rock Scatter	2014	13	0.863	-0.946	393.26 m	339.32 m	Random
		Adjustment	**+0.001**	**+0.003**	**-0.37 m**	**-0.13 m**	
Lithic Scatter	1995-1999	32	0.492	-5.496	300.22 m	147.76 m	99% Yes
Lithic Scatter	2014	32	0.492	-5.501	300.92 m	147.96 m	99% Yes
		Adjustment	**0.000**	**-0.005**	**+0.70 m**	**+0.20 m**	
Sherd & Lithic Scatter	1995-1999	16	1.064	0.487	442.47 m	470.62 m	Random
Sherd & Lithic Scatter	2014	16	1.066	0.504	441.31 m	470.37 m	Random
		Adjustment	**+0.002**	**+0.017**	**-1.16 m**	**-0.25 m**	
Rock Pile	1995-1999	9	0.898	-0.585	162.67 m	146.08 m	Random
Rock Pile	2014	9	0.902	-0.565	160.07 m	144.32 m	Random
		Adjustment	**+0.004**	**+0.020**	**-2.60 m**	**-1.76 m**	

Table A.5. Average elevation adjustment between previous MU locations and 2014 locations per year.

Original Year	GPS Year	# MUs	Mean Elevation	Median Elevation	Min. Elevation	Max. Elevation	Std. Dev.
1995	1995	28	2051.37	2045.04	2026.27	2114.88	20.04
1995	2014	28	2051.52	2045.04	2027.64	2117.85	20.31
		Adjustment	**+0.15**	**0.00**	**+1.37**	**+2.97**	**+0.27**
1997	1997	14	2055.30	2052.18	2038.02	2098.23	15.32
1997	2014	14	2055.64	2052.68	2038.46	2098.23	15.22
		Adjustment	**+0.34**	**+0.50**	**+0.44**	**0.00**	**-0.10**
1999	1999	64	2078.18	2061.03	2015.63	2164.29	37.07
1999	2014	64	2078.34	2061.49	2015.63	2164.29	36.99
		Adjustment	**+0.16**	**+0.46**	**0.00**	**0.00**	**-0.08**
2003	2003	1	2081.06	--	--	--	--
2003	2014	1	2080.95	--	--	--	--
		Adjustment	**-0.11**	**--**	**--**	**--**	**--**
2008	2008	2	2127.06	2127.06	2055.12	2199.00	71.94
2008	2014	2	2127.35	2127.35	2055.63	2199.06	71.72
		Adjustment	**+0.29**	**+0.29**	**+0.51**	**+0.06**	**-0.22**
2009	2009	2	2162.72	2162.72	2071.05	2254.40	91.67
2009	2014	2	2162.71	2162.71	2071.05	2254.37	91.66
		Adjustment	**-0.01**	**-0.01**	**0.00**	**-0.03**	**-0.01**
2010	2010	2	2062.97	2062.97	2062.60	2063.33	0.36
2010	2014	2	2063.10	2063.10	2062.94	2063.25	0.16
		Adjustment	**+0.13**	**+0.13**	**+0.34**	**-0.08**	**-0.20**
2012	2012	5	2203.44	2210.63	2177.34	2221.62	15.27
2012	2014	5	2203.44	2210.63	2177.39	2221.63	15.25
		Adjustment	**0.00**	**0.00**	**+0.05**	**+0.01**	**-0.02**

Table A.6. Average slope adjustment between previous MU locations and 2014 locations per year.

Original Year	GPS Year	# MUs	Mean Slope	Median Slope	Min. Slope	Max. Slope	Std. Dev.
1995	1995	28	2.86	2.29	0.76	8.17	1.72
1995	2014	28	2.74	2.31	0.79	5.63	1.29
		Adjustment	**-0.12**	**+0.02**	**+0.03**	**-2.54**	**-0.43**
1997	1997	14	4.05	2.88	1.07	9.31	2.51
1997	2014	14	3.72	2.51	1.11	8.67	2.47
		Adjustment	**-0.33**	**-0.37**	**+0.04**	**-0.64**	**-0.04**
1999	1999	64	3.35	2.58	0.46	12.62	2.26
1999	2014	64	3.50	2.64	0.80	12.63	2.45
		Adjustment	**+0.15**	**+0.06**	**+0.34**	**+0.01**	**+0.19**
2003	2003	1	3.44	--	--	--	--
2003	2014	1	3.29	--	--	--	--
		Adjustment	**-0.15**	**--**	**--**	**--**	
2008	2008	2	4.48	4.48	3.72	5.24	0.76
2008	2014	2	4.32	4.32	3.87	4.77	0.45
		Adjustment	**-0.16**	**-0.16**	**+0.15**	**-0.47**	**-0.31**
2009	2009	2	2.19	2.19	2.05	2.33	0.14
2009	2014	2	2.11	2.11	2.06	2.16	0.05
		Adjustment	**-0.08**	**-0.08**	**+0.01**	**-0.17**	**-0.09**
2010	2010	2	5.53	5.53	5.33	5.72	0.20
2010	2014	2	5.62	5.62	5.53	5.70	0.09
		Adjustment	**+0.09**	**+0.09**	**+0.20**	**-0.02**	**-0.11**
2012	2012	5	4.15	2.45	1.13	9.71	3.12
2012	2014	5	4.02	2.46	1.13	9.57	3.06
		Adjustment	**-0.13**	**+0.01**	**0.00**	**-0.14**	**-0.06**

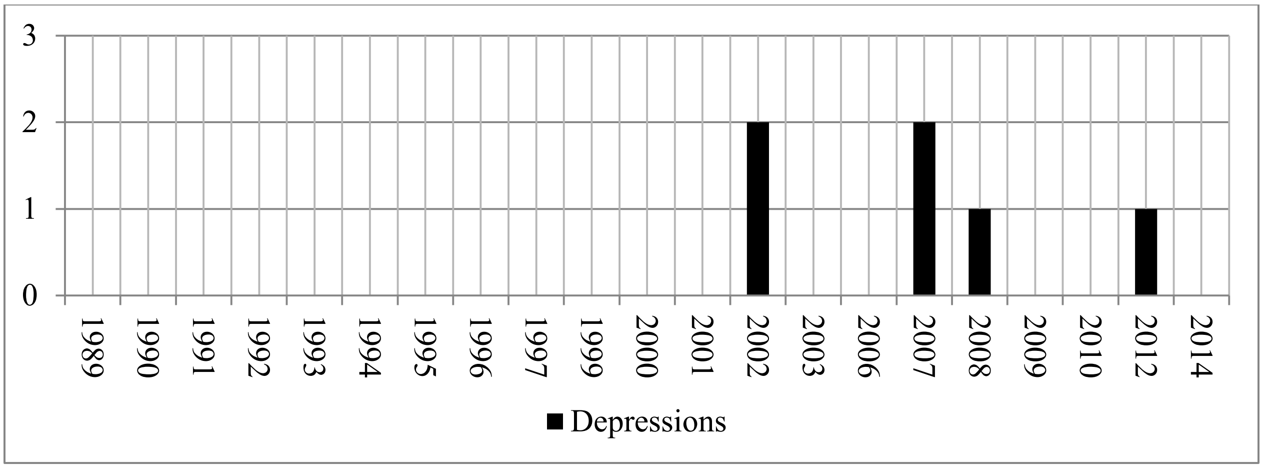
Table A.7. Average elevation adjustment between previous MU locations and 2014 locations per feature type.

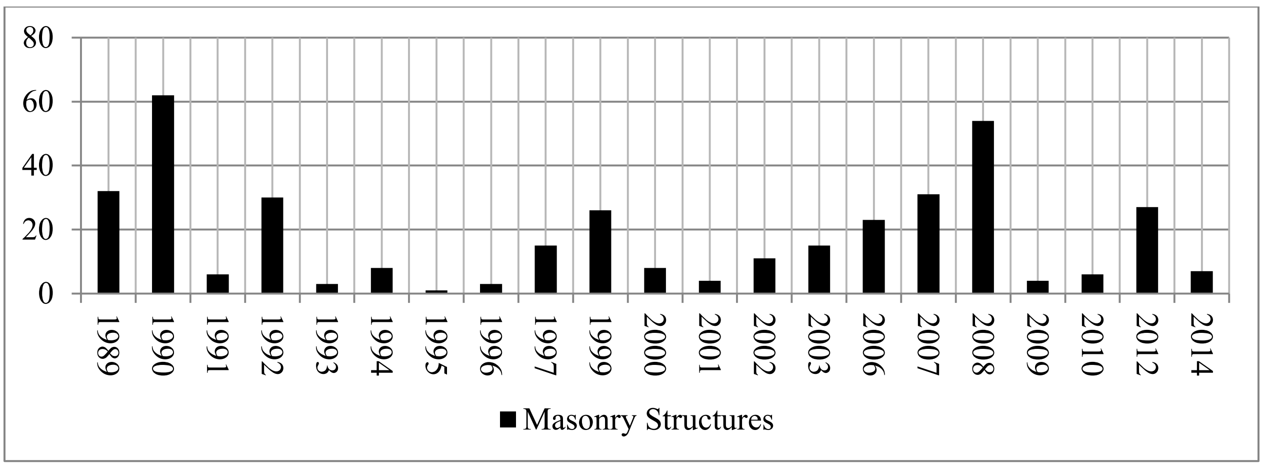
Feature Type	GPS Year(s)	# MUs	Mean Elevation	Median Elevation	Min. Elevation	Max. Elevation	Std. Dev.
Masonry Structure	1997-2012	10	2169.50	2197.91	2054.96	2254.43	65.52
Masonry Structure	2014	10	2169.52	2197.73	2055.96	2254.43	65.30
		Adjustment	**+0.02**	**-0.18**	**+1.00**	**0.00**	**-0.22**
Wood Hogan	1995-1999	2	2048.07	2048.07	2026.09	2070.05	21.98
Wood Hogan	2014	2	2048.89	2048.89	2027.68	2070.10	21.21
		Adjustment	**+0.82**	**+0.82**	**+1.59**	**+0.05**	**+0.77**
Brush Structure	1999	9	2065.58	2059.88	2034.05	2129.23	27.39
Brush Structure	2014	9	2065.69	2059.88	2034.05	2129.23	27.35
		Adjustment	**+0.11**	**0.00**	**0.00**	**0.00**	**-0.04**
Sweat Lodge	1999	4	2046.26	2056.12	2015.63	2057.20	17.70
Sweat Lodge	2014	4	2046.33	2056.25	2015.63	2057.20	17.74
		Adjustment	**+0.07**	**+0.13**	**0.00**	**0.00**	**+0.04**
Fire-Cracked-Rock Pile	1997-1999	20	2085.03	2069.67	2040.09	2164.29	33.55
Fire-Cracked-Rock Pile	2014	20	2085.44	2069.95	2040.09	2164.29	33.30
		Adjustment	**+0.41**	**+0.28**	**0.00**	**0.00**	**-0.25**
Fire-Cracked-Rock Scatter	1995-2010	13	2078.01	2063.53	2042.70	2160.84	32.81
Fire-Cracked-Rock Scatter	2014	13	2078.06	2063.27	2043.01	2160.84	32.79
		Adjustment	**+0.05**	**-0.26**	**+0.31**	**0.00**	**-0.02**
Lithic Scatter	1995-1999	32	2065.57	2047.82	2035.46	2159.61	34.93
Lithic Scatter	2014	32	2065.80	2048.04	2035.34	2160.33	35.08
		Adjustment	**+0.23**	**+0.22**	**-0.12**	**+0.72**	**+0.15**
Sherd & Lithic Scatter	1995-1999	16	2055.06	2046.95	2016.92	2144.46	29.31
Sherd & Lithic Scatter	2014	16	2055.37	2047.59	2017.78	2144.00	29.00
		Adjustment	**+0.31**	**+0.64**	**+0.86**	**-0.46**	**-0.31**
Rock Pile	1995-1999	9	2066.14	2048.17	2042.80	2110.73	27.25
Rock Pile	2014	9	2066.13	2047.53	2042.88	2110.73	27.26
		Adjustment	**-0.01**	**-0.64**	**+0.08**	**0.00**	**+0.01**

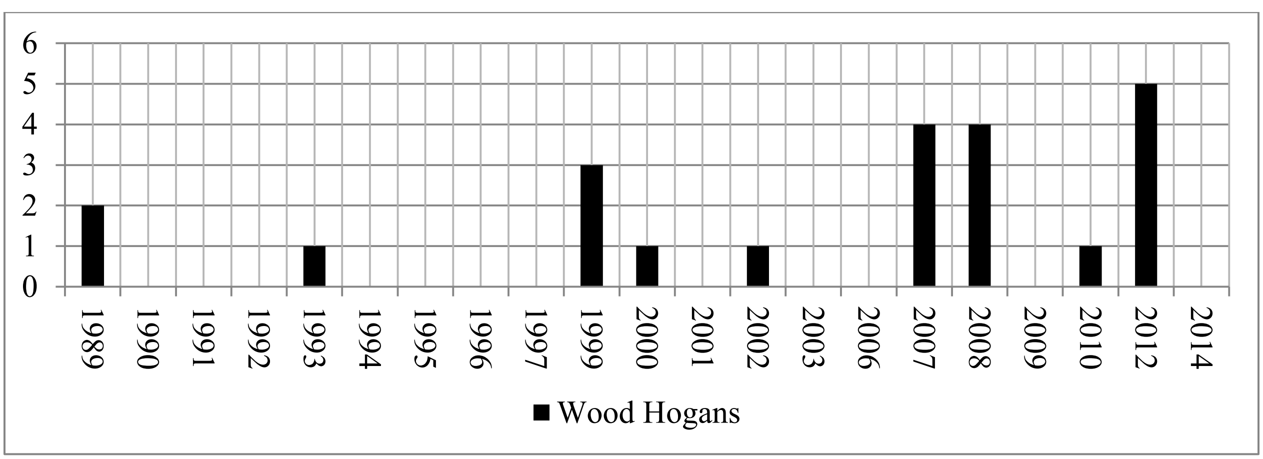
Table A.8. Average slope adjustment between previous MU locations and 2014 locations per feature type.

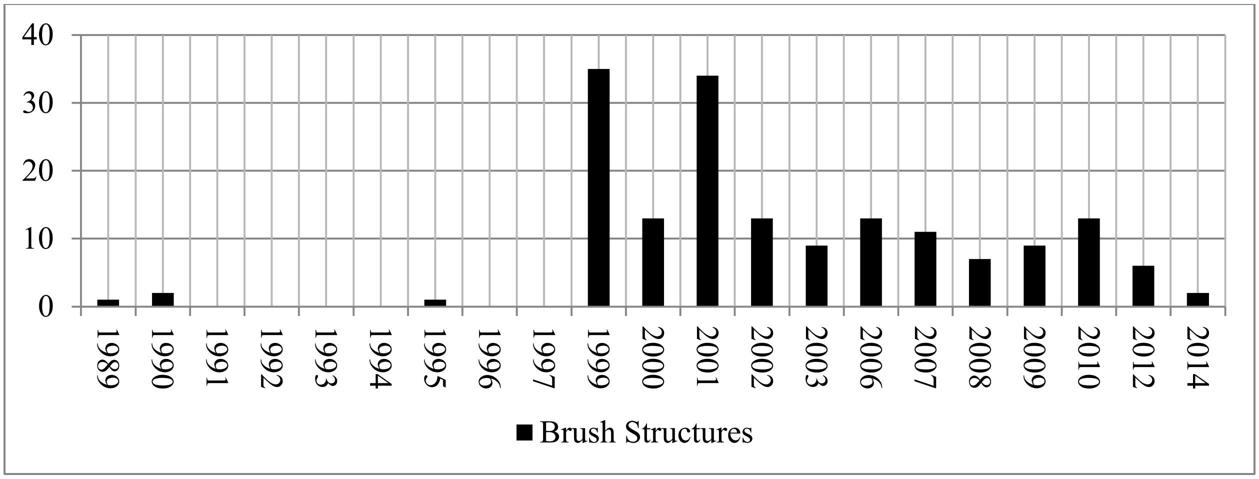
Feature Type	GPS Year(s)	# MUs	Mean Slope	Median Slope	Min. Slope	Max. Slope	Std. Dev.
Masonry Structure	1997-2012	10	3.73	2.41	1.21	10.06	2.59
Masonry Structure	2014	10	3.53	2.52	1.21	10.06	2.45
		Adjustment	**-0.20**	**+0.11**	**0.00**	**0.00**	**-0.14**
Wood Hogan	1995-1999	2	1.39	1.39	0.61	2.17	0.78
Wood Hogan	2014	2	1.62	1.62	0.82	2.42	0.80
		Adjustment	**+0.23**	**+0.23**	**+0.21**	**+0.25**	**+0.02**
Brush Structure	1999	9	3.59	3.34	1.54	9.26	2.16
Brush Structure	2014	9	3.75	3.71	1.54	9.26	2.18
		Adjustment	**+0.16**	**+0.37**	**0.00**	**0.00**	**+0.02**
Sweat Lodge	1999	4	3.59	3.40	1.91	5.65	1.63
Sweat Lodge	2014	4	3.51	3.31	1.77	5.65	1.70
		Adjustment	**-0.08**	**-0.09**	**-0.14**	**0.00**	**+0.07**
Fire-Cracked-Rock Pile	1997-1999	20	2.72	2.56	0.67	6.37	1.24
Fire-Cracked-Rock Pile	2014	20	2.99	2.59	0.67	9.46	1.75
		Adjustment	**+0.27**	**+0.03**	**0.00**	**+3.09**	**+0.51**
Fire-Cracked-Rock Scatter	1995-2010	13	2.52	2.07	1.14	5.73	1.41
Fire-Cracked-Rock Scatter	2014	13	2.50	1.97	1.36	5.73	1.46
		Adjustment	**-0.02**	**-0.10**	**+0.22**	**0.00**	**+0.05**
Lithic Scatter	1995-1999	32	3.05	2.52	0.47	7.25	1.83
Lithic Scatter	2014	32	3.04	2.52	0.84	8.23	1.97
		Adjustment	**-0.01**	**0.00**	**+0.37**	**0.98**	**+0.14**
Sherd & Lithic Scatter	1995-1999	16	4.05	4.07	0.62	9.33	2.56
Sherd & Lithic Scatter	2014	16	4.07	3.59	0.80	8.51	2.51
		Adjustment	**+0.02**	**-0.48**	**+0.18**	**-0.82**	**-0.05**
Rock Pile	1995-1999	9	3.53	2.87	1.56	7.12	1.92
Rock Pile	2014	9	3.72	3.29	1.66	7.12	1.84
		Adjustment	**+0.19**	**+0.42**	**+0.10**	**0.00**	**-0.08**

Appendix B – Feature Type Discoveries per Year





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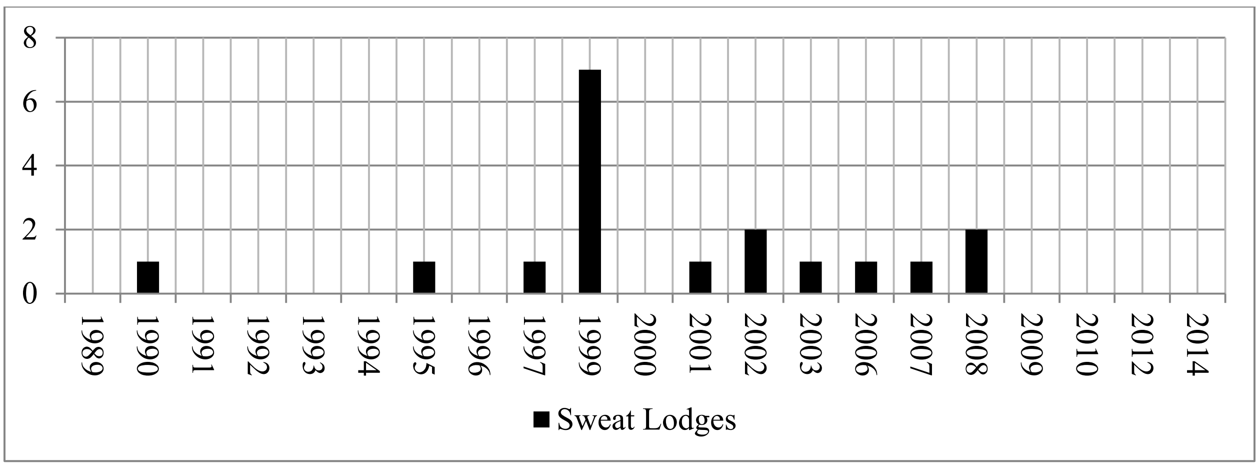
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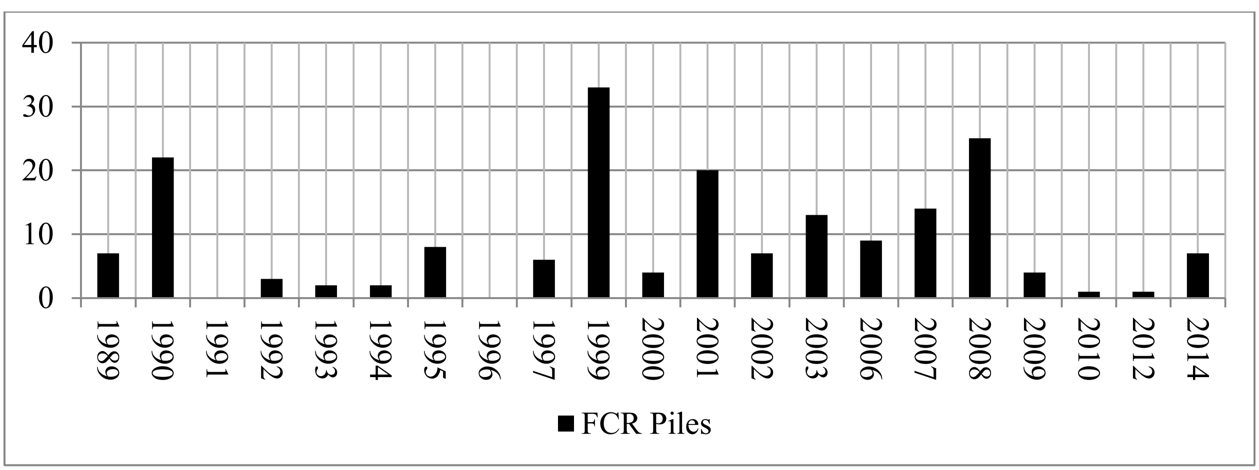
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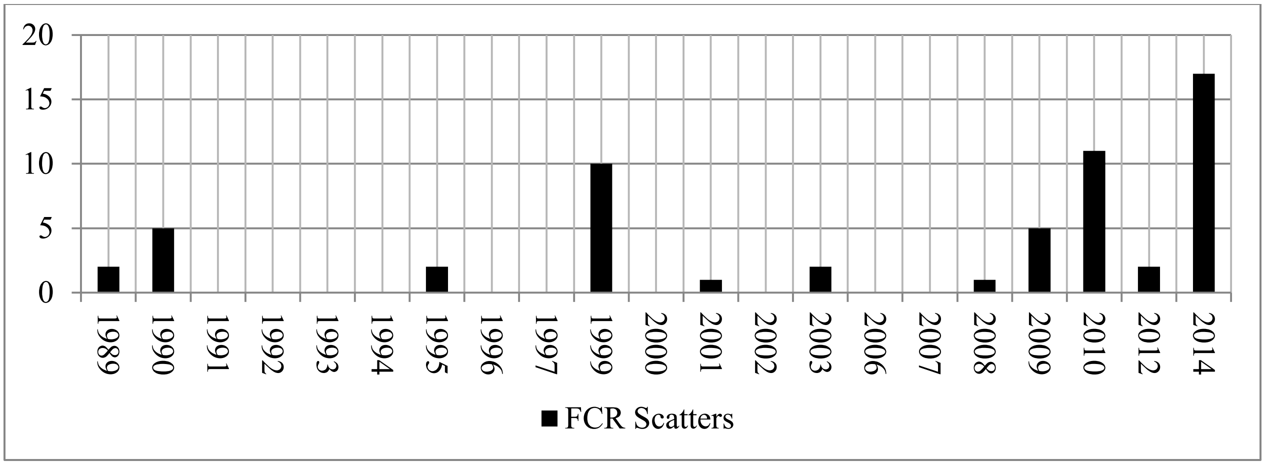
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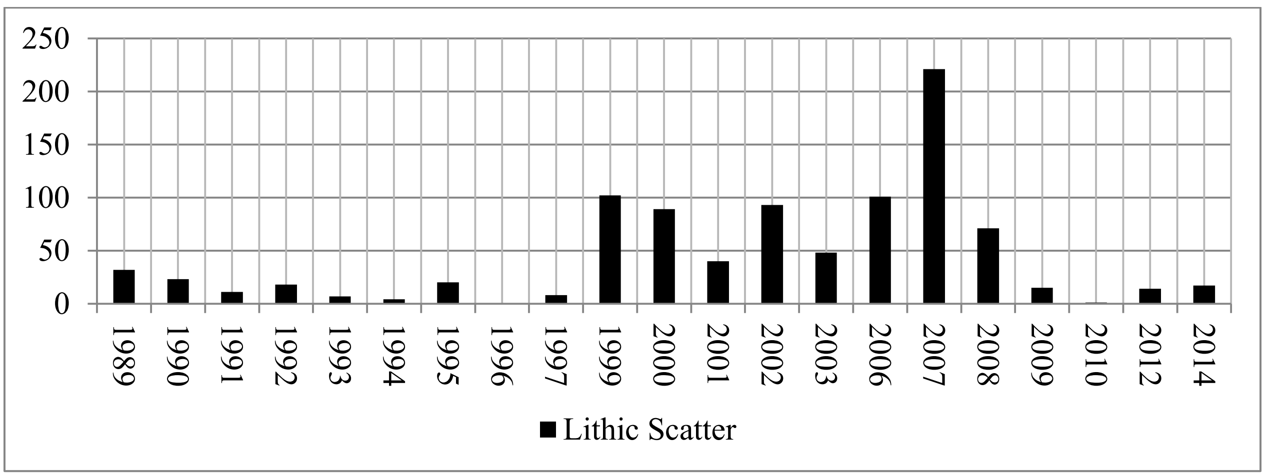
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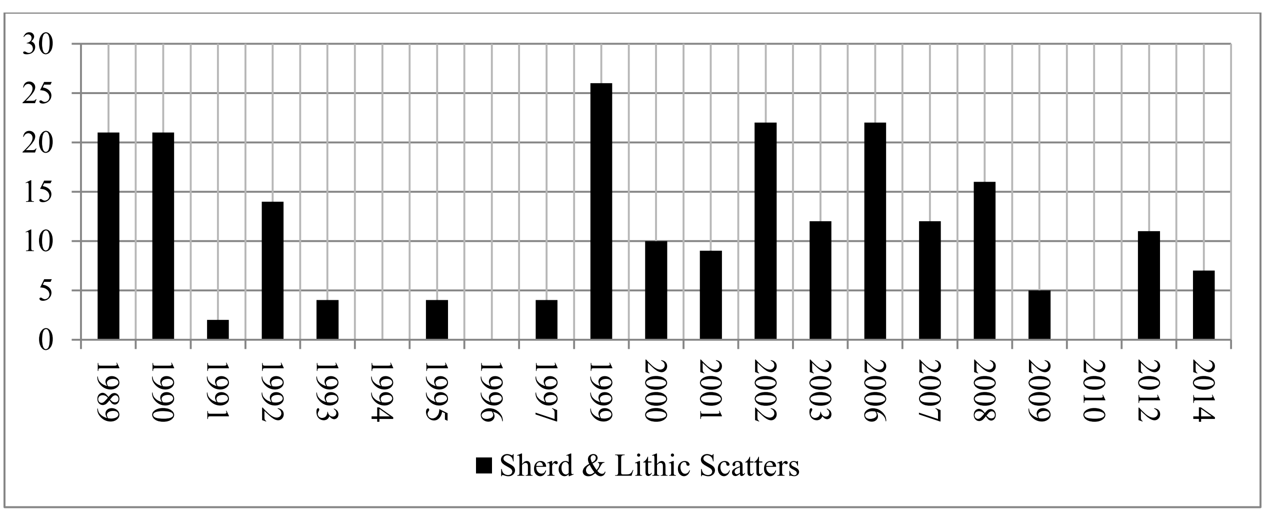
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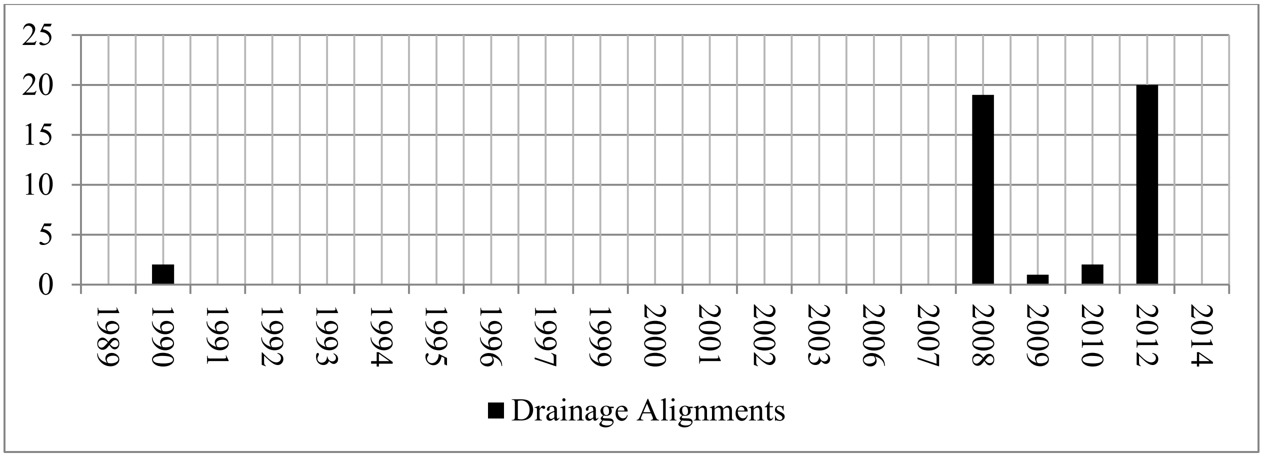
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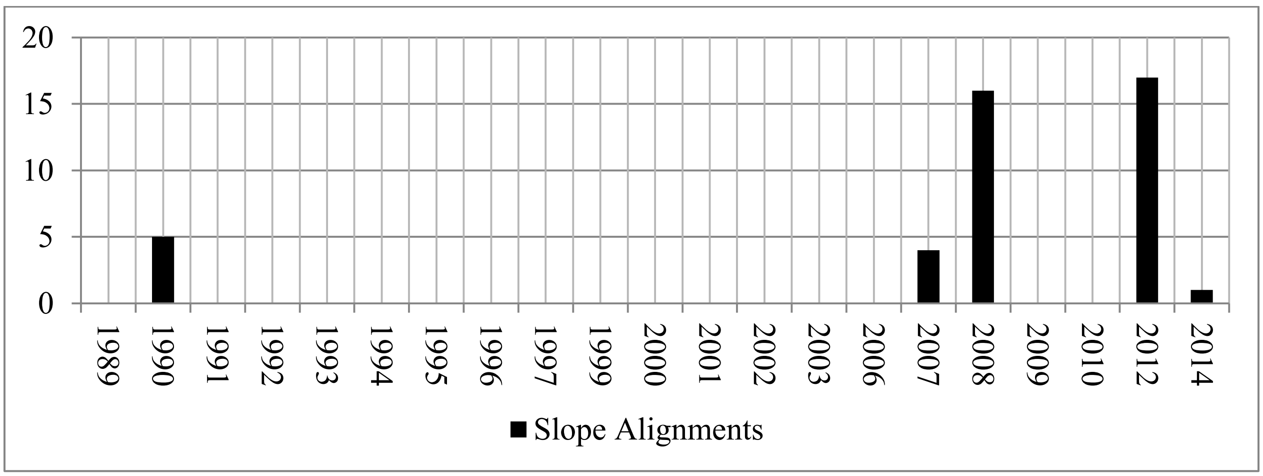
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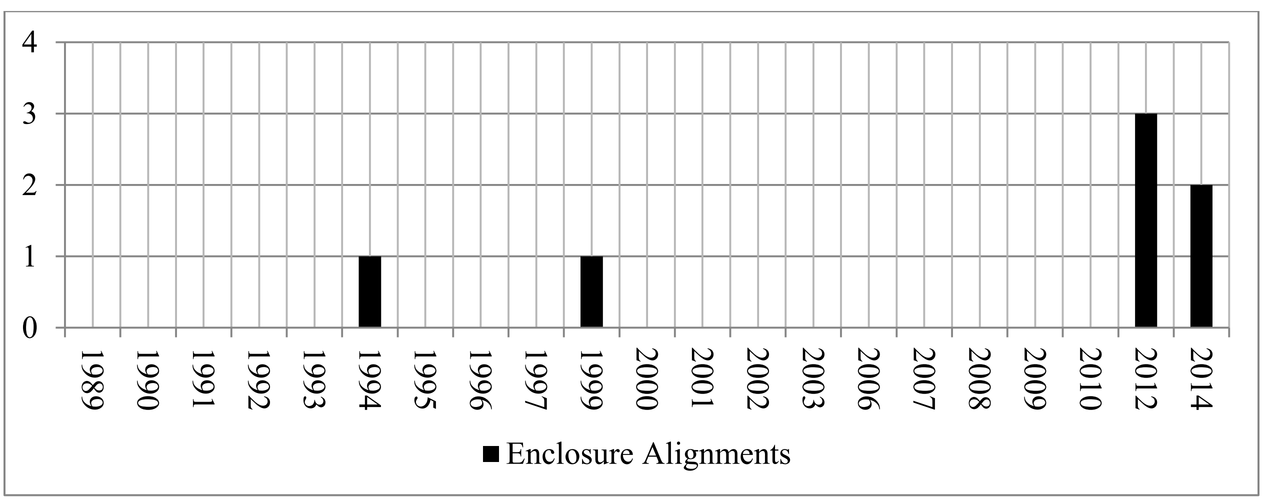
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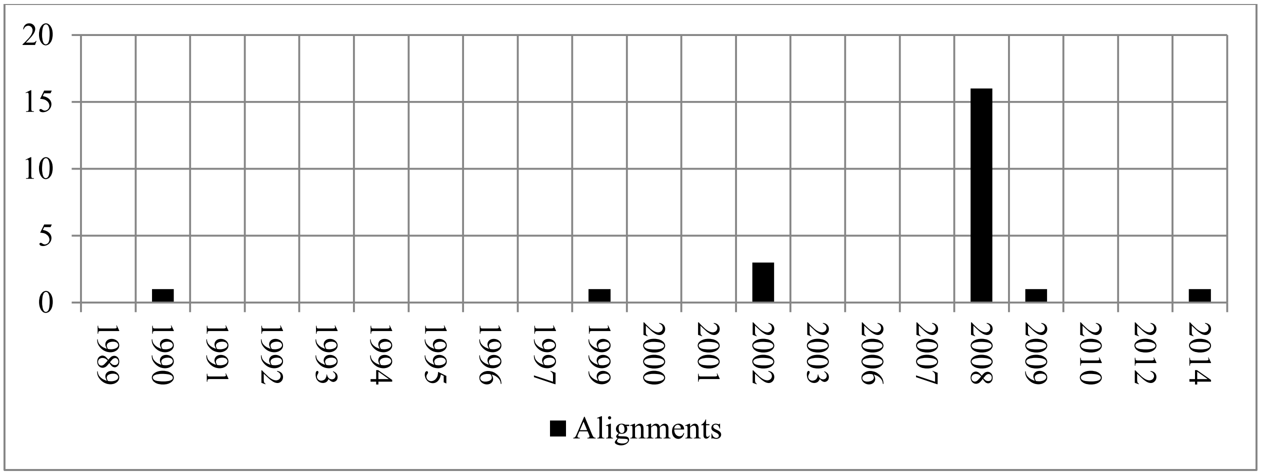
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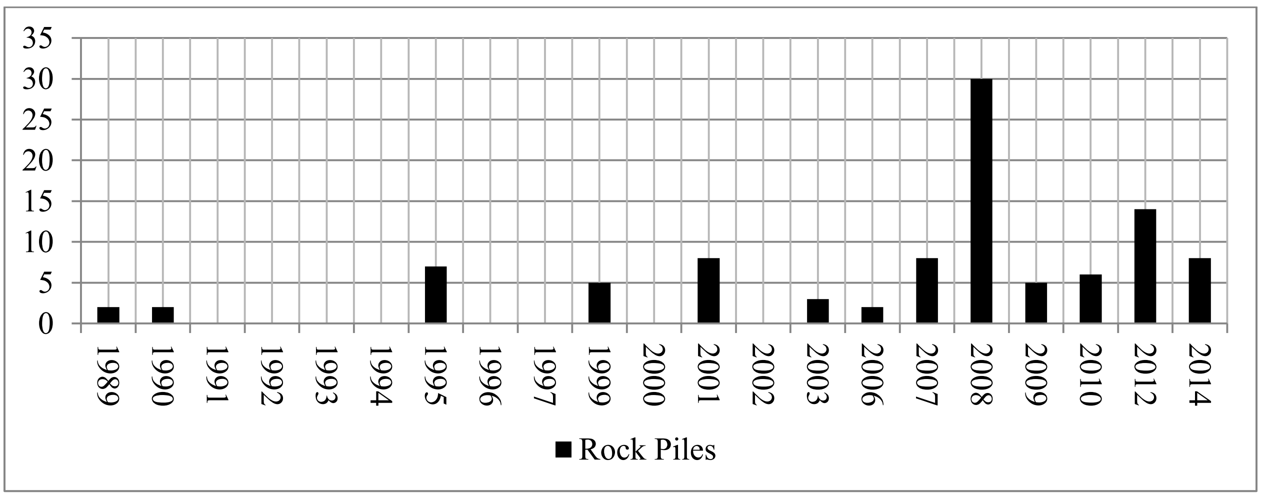
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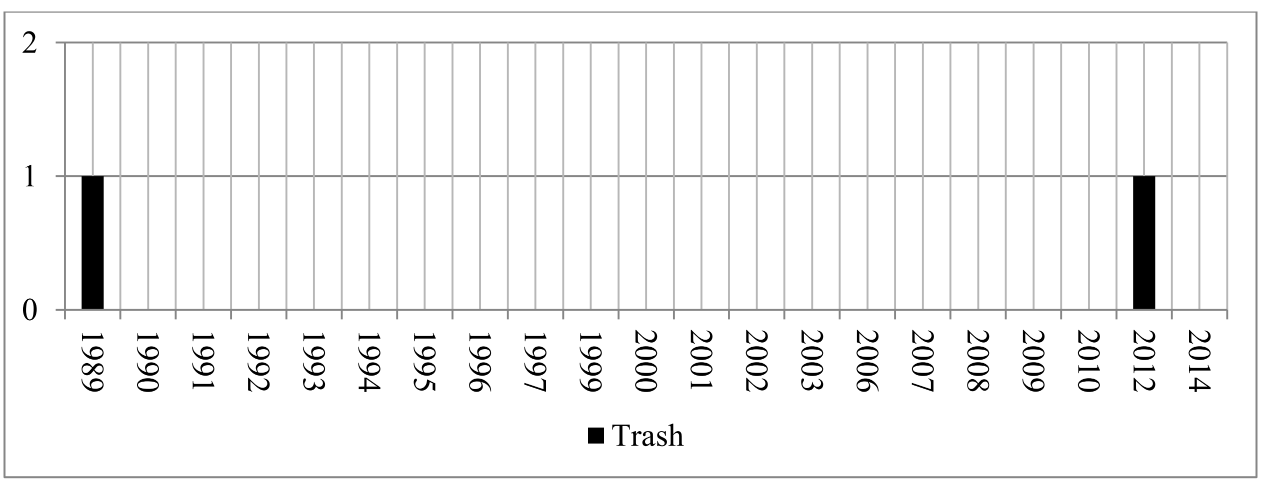
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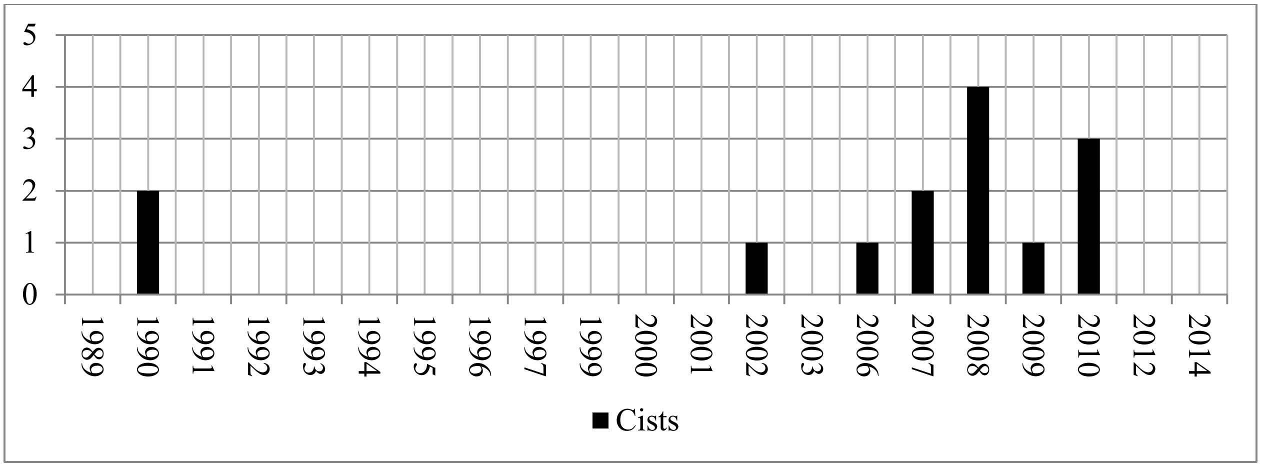
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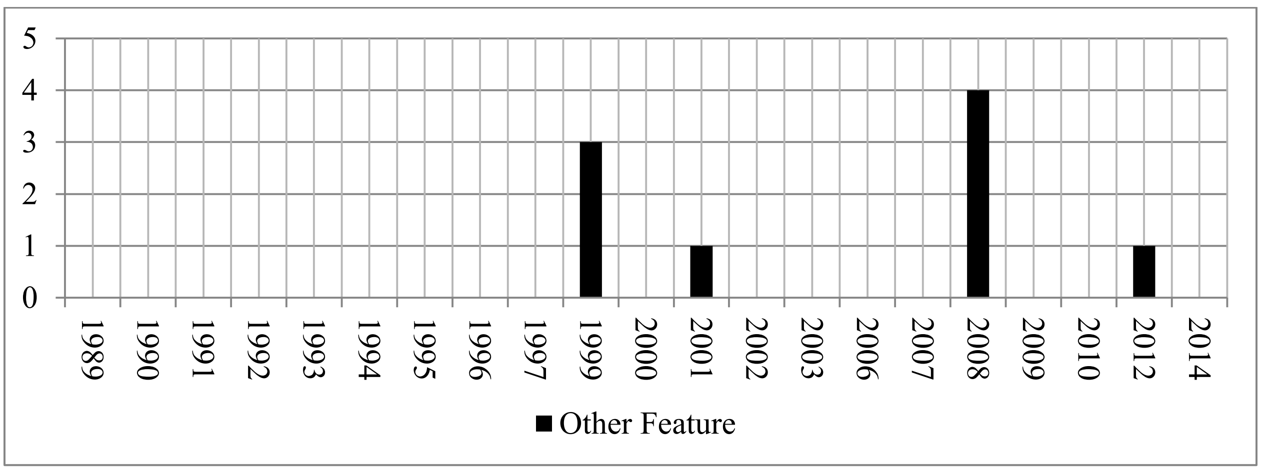
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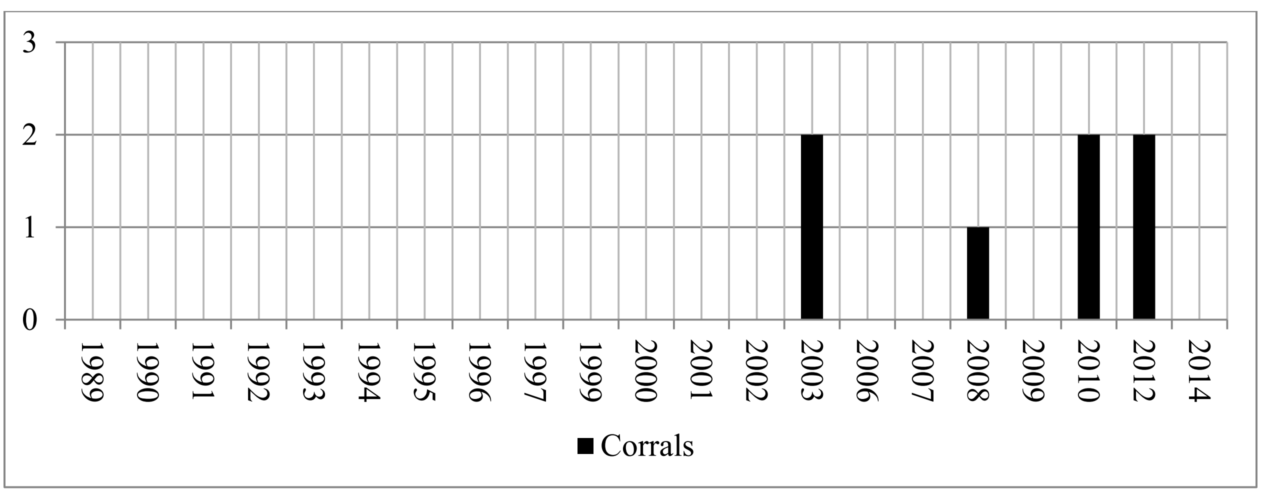
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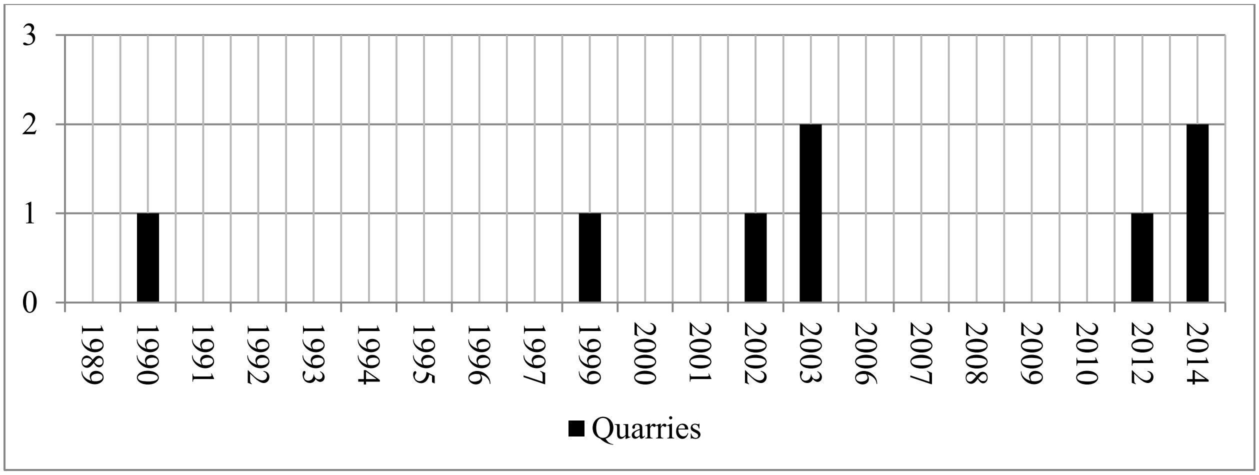
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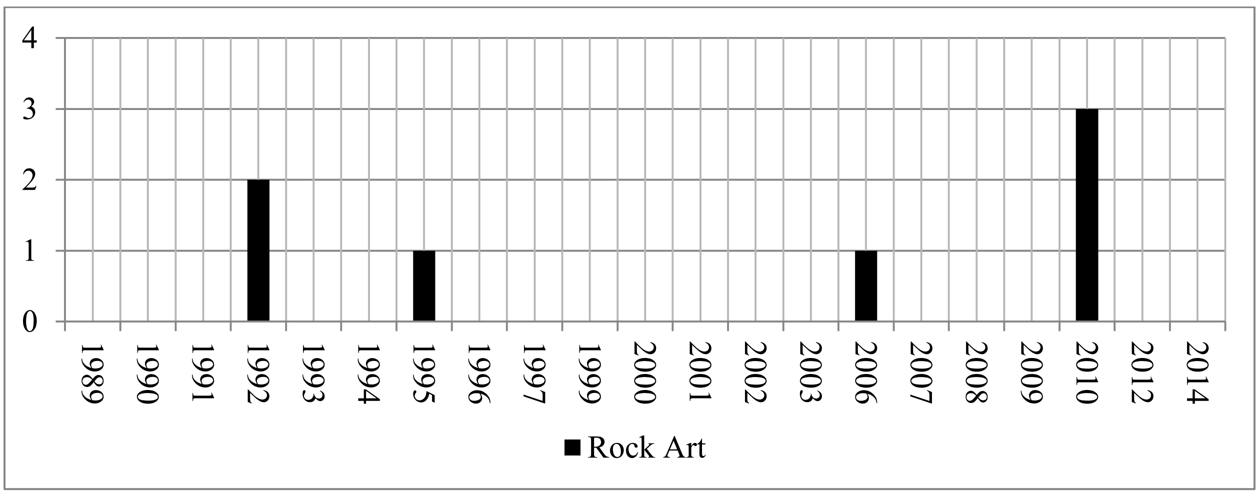
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Table B.1. Yearly recording rate of select feature types.

Year	Masonry Structures	Wood Hogans	Brush Structures	Sweat Lodges	FCR Piles	FCR Scatters	Lithic Scatters	Sherd & Lithic Scatters	Rock Piles
1989	32	2	1	0	7	2	32	21	2
1990	62	0	2	1	22	5	23	21	2
1991	6	0	0	0	0	0	11	2	0
1992	30	0	0	0	3	0	18	14	0
1993	3	1	0	0	2	0	7	4	0
1994	8	0	0	0	2	0	4	0	0
1995	1	0	1	1	8	2	20	4	7
1996	3	0	0	0	0	0	0	0	0
1997	15	0	0	1	6	0	8	4	0
1999	26	3	35	7	33	10	102	26	5
2000	8	1	13	0	4	0	89	10	0
2001	4	0	34	1	20	1	40	9	8
2002	11	1	13	2	7	0	93	22	0
2003	15	0	9	1	13	2	48	12	3
2006	23	0	13	1	9	0	101	22	2
2007	31	4	11	1	14	0	221	12	8
2008	54	4	7	2	25	1	71	16	30
2009	4	0	9	0	4	5	15	5	5
2010	6	1	13	0	1	11	1	0	6
2012	27	5	6	0	1	2	14	11	14
2014	7	0	2	0	7	17	17	7	8